Enhanced Geothermal Systems (EGS)
- Case study Groß Schönebeck -

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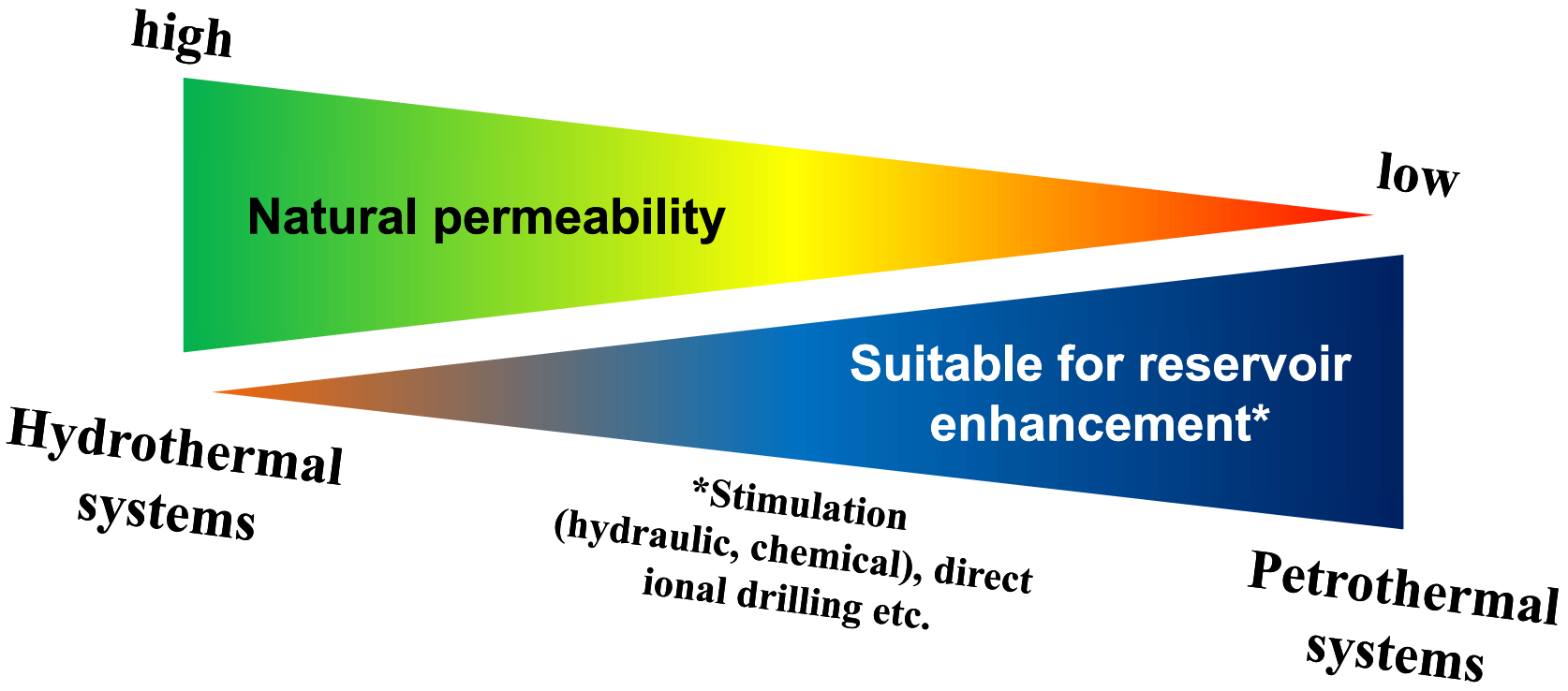
Reservoir systems

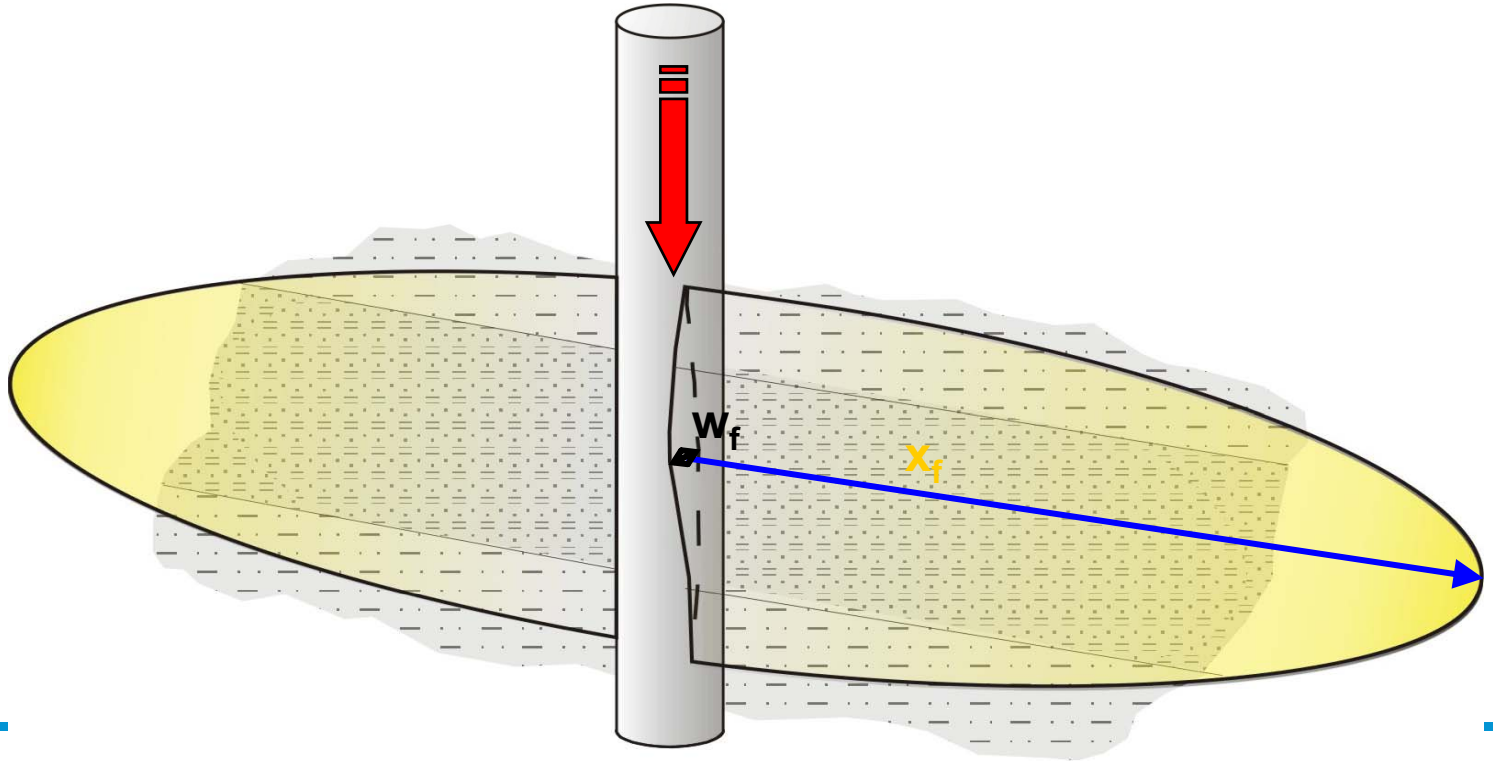
Enhanced geothermal systems



Hydraulic stimulation technique: waterfracs (WF)

water / low viscous gels:	η = 1 - 10 mPa s
without proppants or small proppant concentration: c	= 50 - 200 g/l
long fractures:	$x_f \leq 250$ m
small width:	$w_f \sim 1$ mm

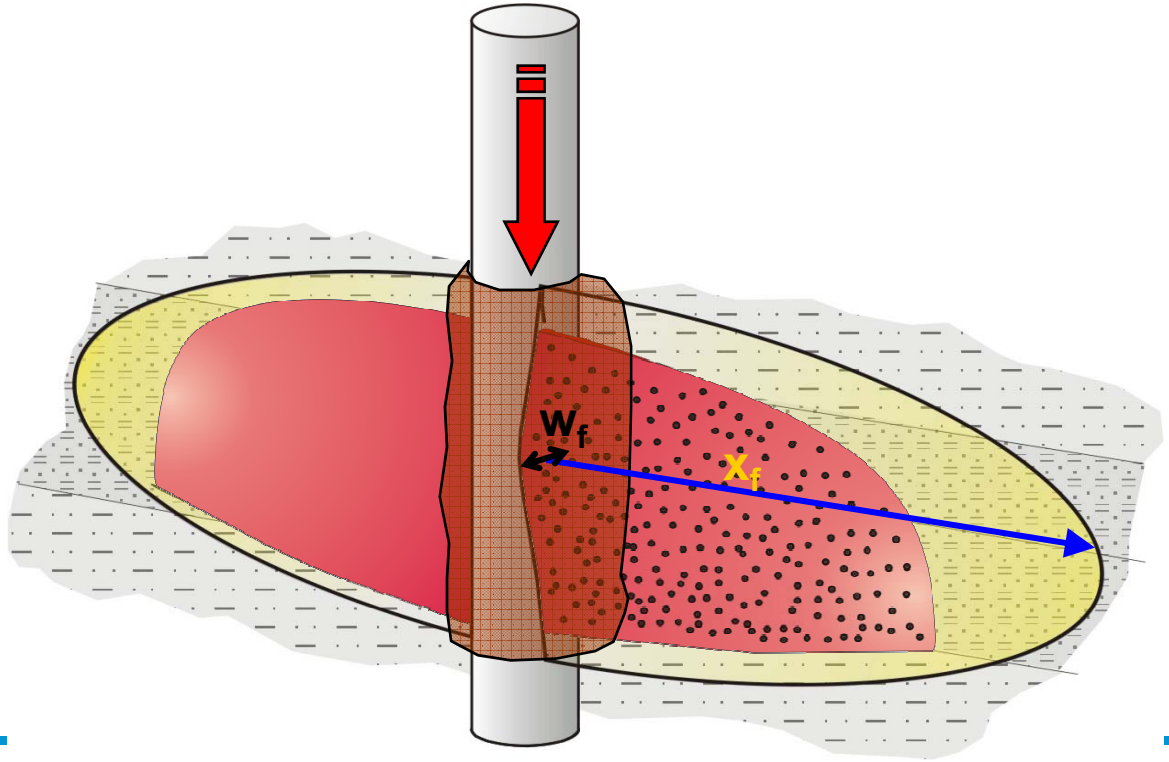
- reduction in costs compared or HPF
- application is limited to reservoirs with small permeability
- success is dependent on the self propping potential of the reservoir rock



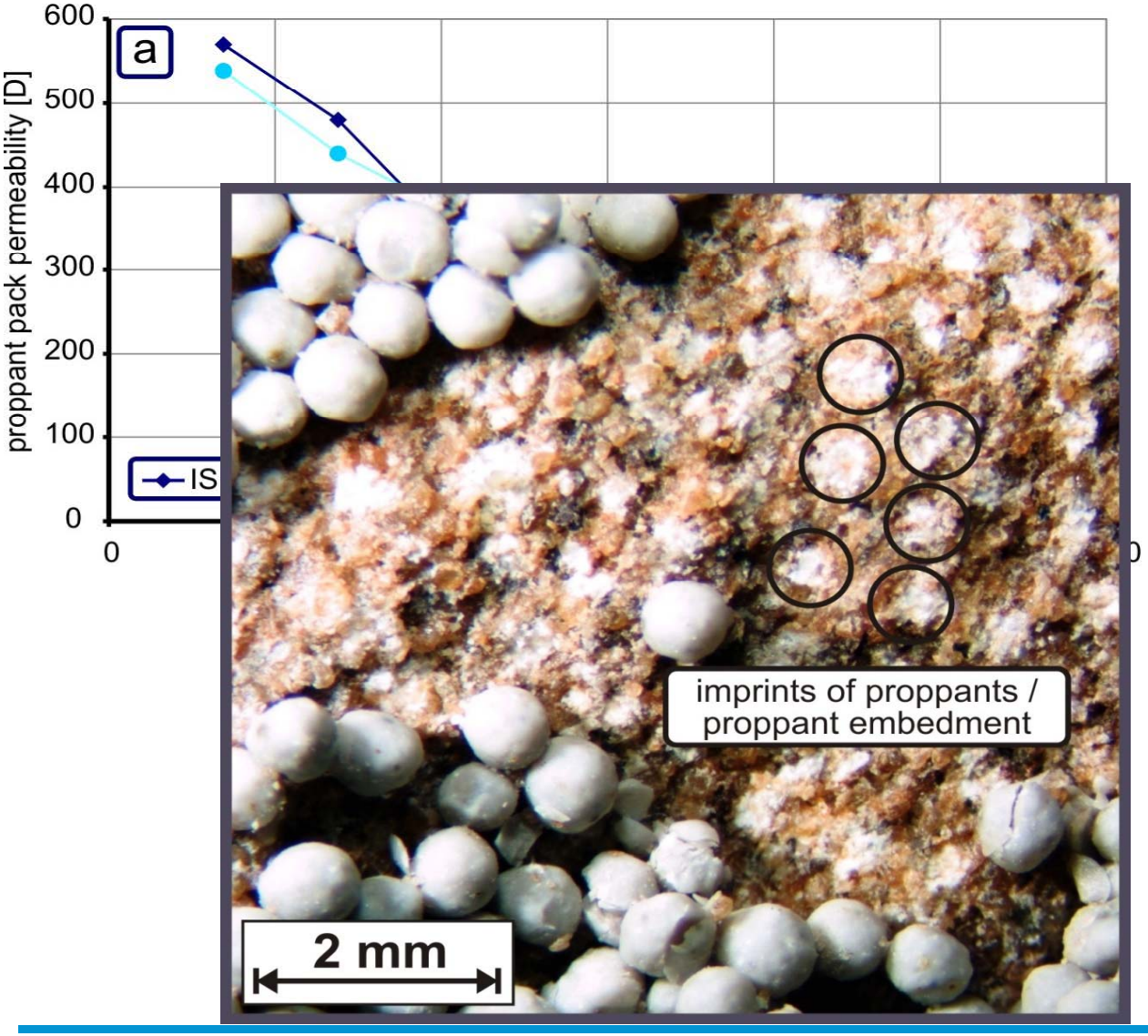
Hydraulic stimulation technique: hydraulic proppant fracs (HPF)

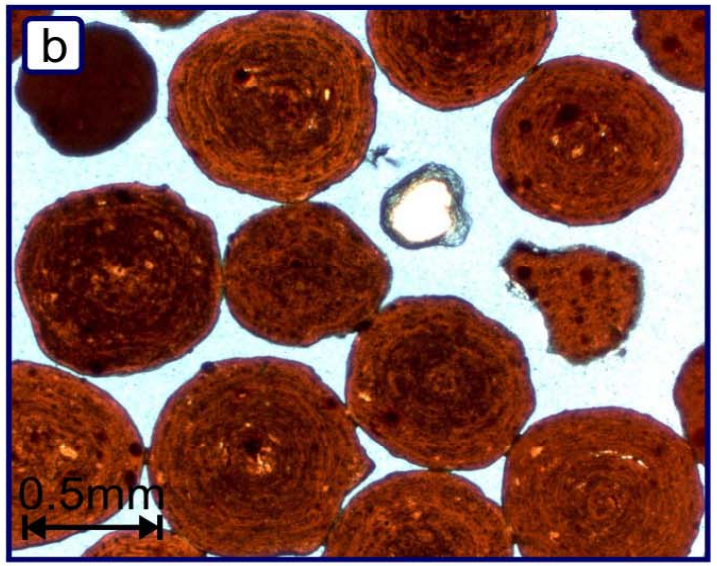
high viscous gels:		η = 100 - 1000 mPa s
high proppant concentration:	c	= 200 - 2000 g/l
shorter fractures:		x_f = 50 - 150 m
big width:		w_f = 5 - 25 mm

- wide range of formations (permeabilities) can be treated
- good control of stimulation parameters
- wellbore skin can be bypassed
- treatments are more expensive



What are Proppants?



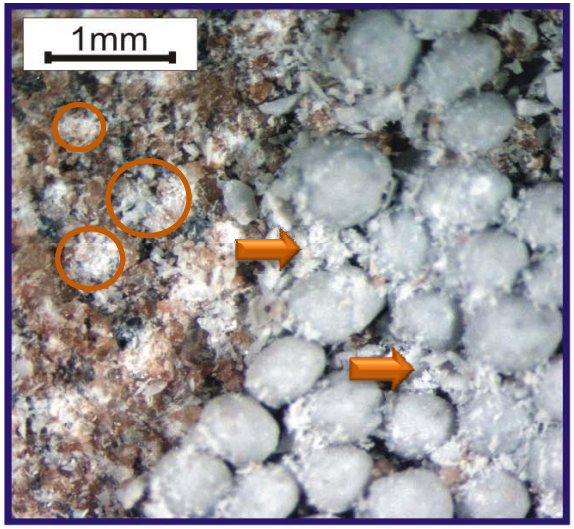


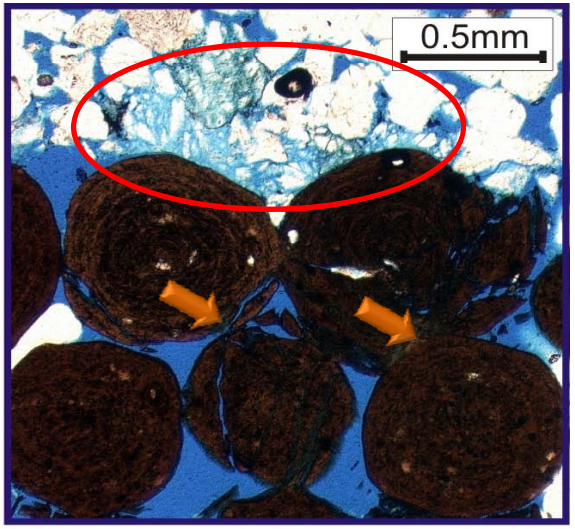
Optical Investigation of Rock-Proppant Interaction

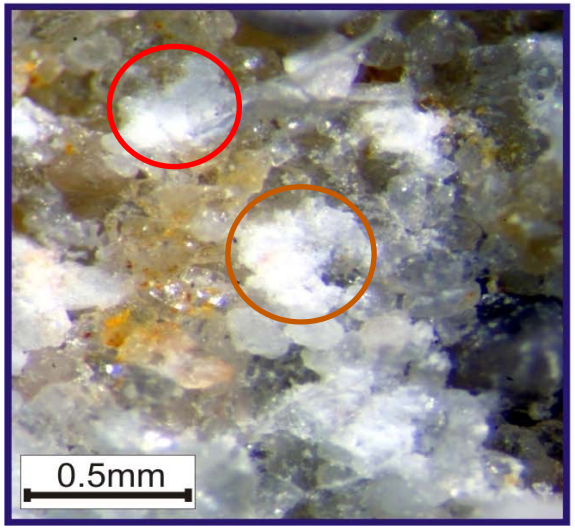
imprints of proppants
proppant embedment

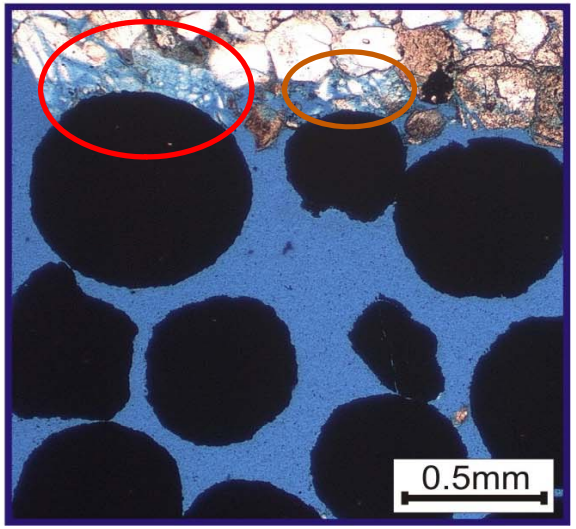
fines blocking pores of proppant pack

proppant embedment and fines production at the fracture face









abundant fines blocking pores at Bentheim ss fracture face

proppant crushing initiated at PP-contacts

smaller amount of fines at Flechtingen ss fracture face

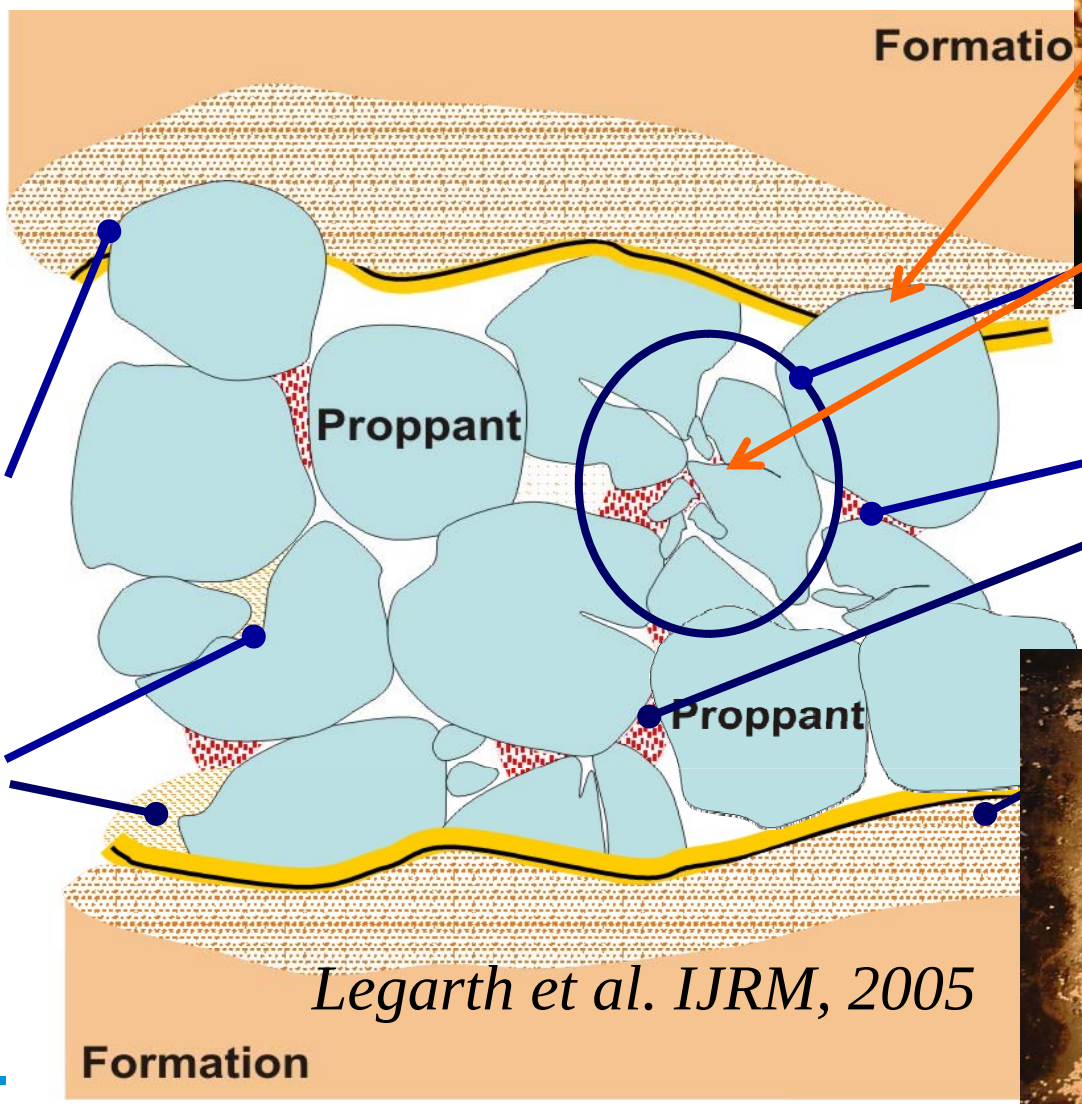
amount of crushed HSP is small compared to ISP

Formation Damage Mechanisms in a Propped Fracture

generation of a Fracture Face Skin - FFS

filtration of frac fluids
filter cake buildup
relative perm. changes
gas condensation

sedimentation of fines

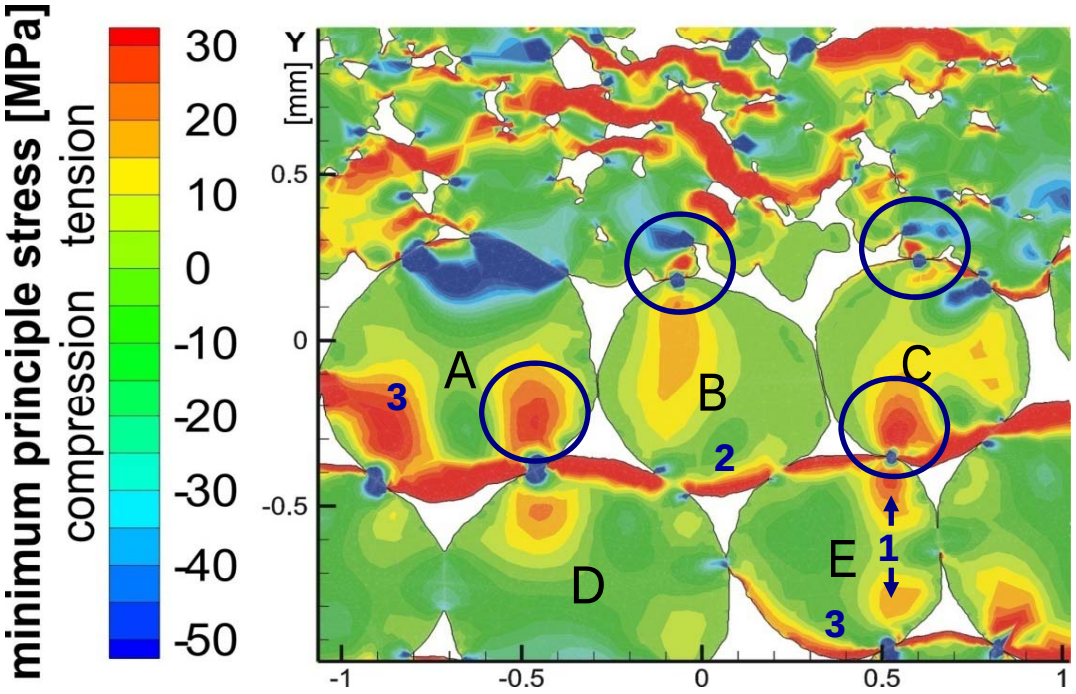


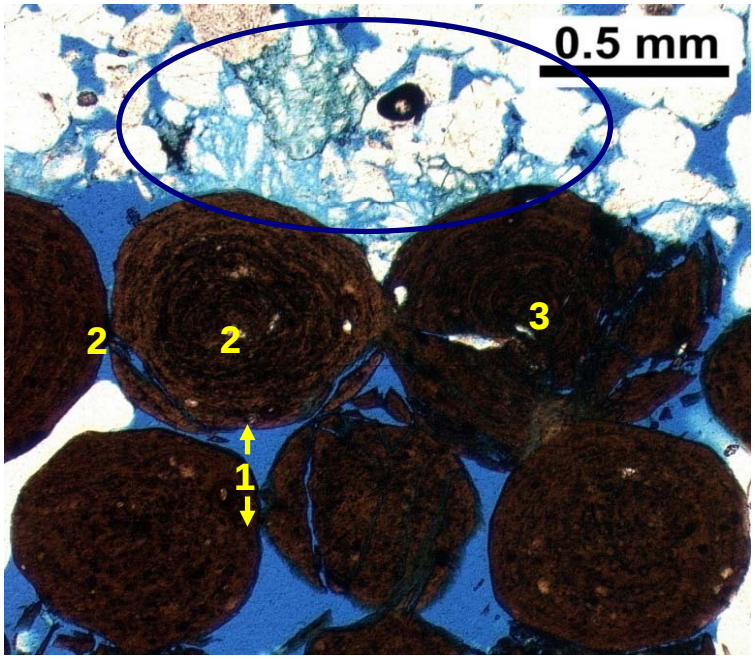
gel residues and chemical precipitation

Legarth et al. IJRM, 2005

Numerical Stress Modelling: Stress and Fracture Pattern

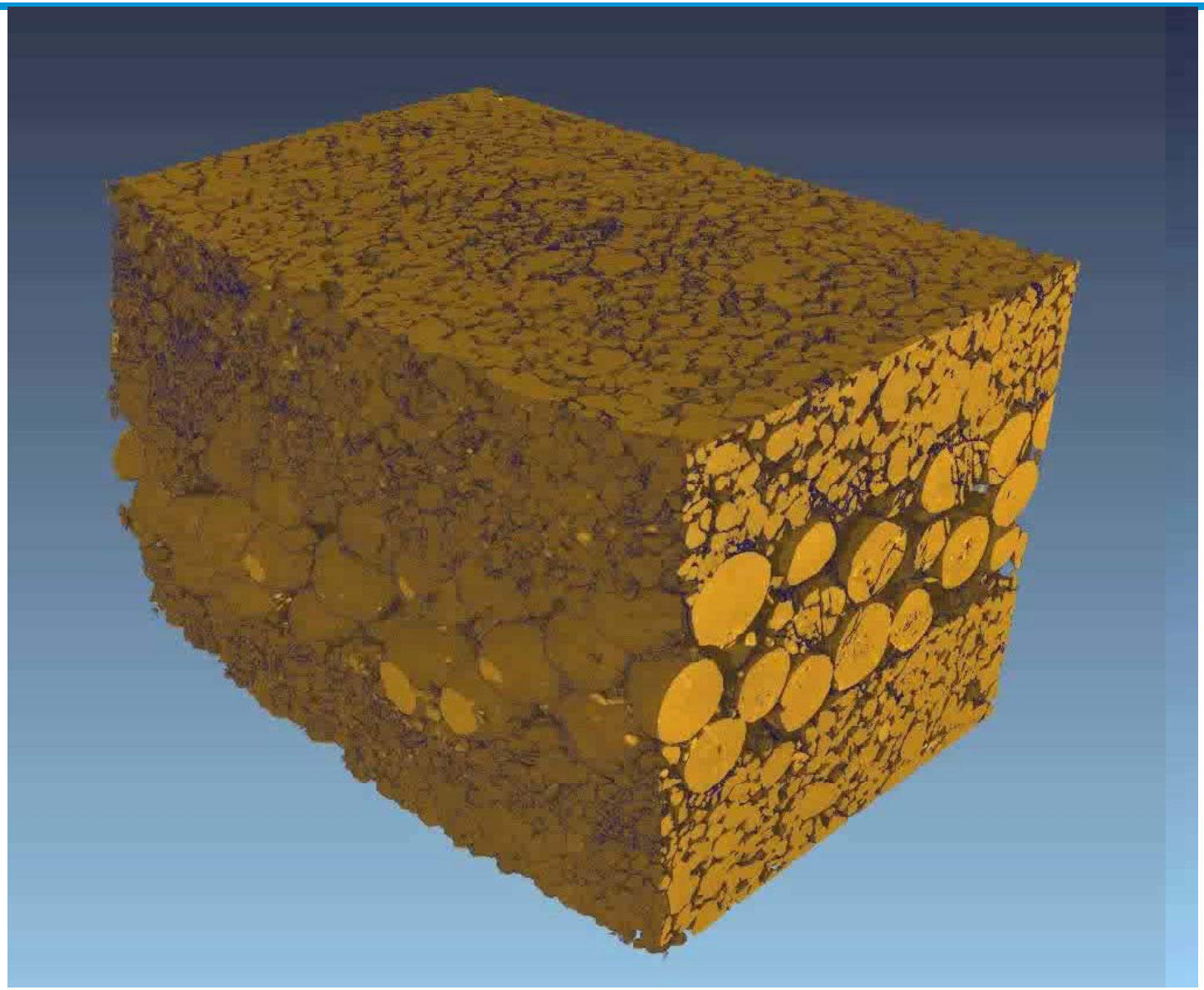
σ_{diff} = 50 MPa





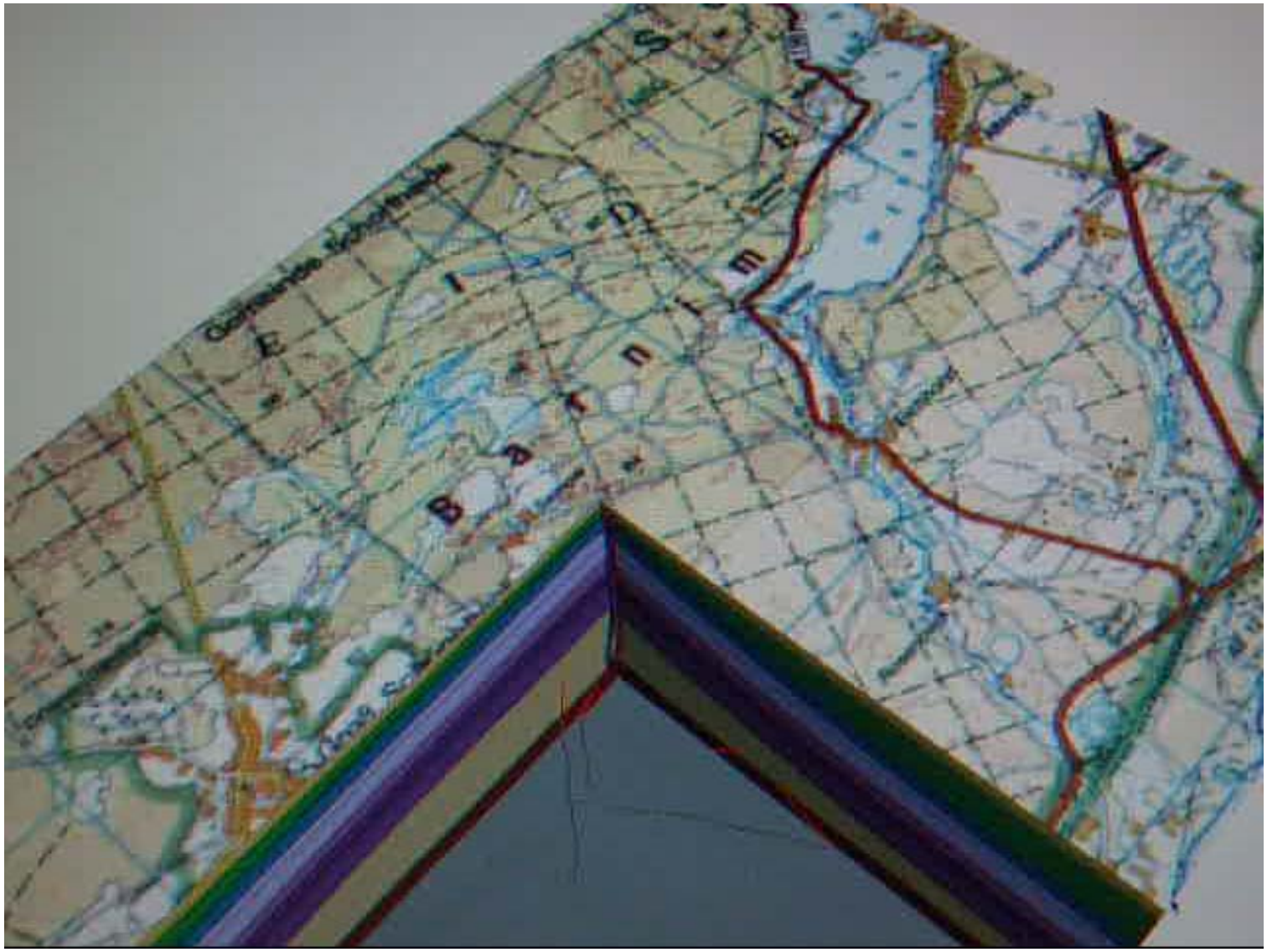
- highly localized tensile stress near contacts / surfaces
- cleavage of proppants / disintegration of quartz grains
- fines production and pore blocking at the fracture face explains the mechanically induced FFS

CT Scan of Proppant Embedment and Fines Production

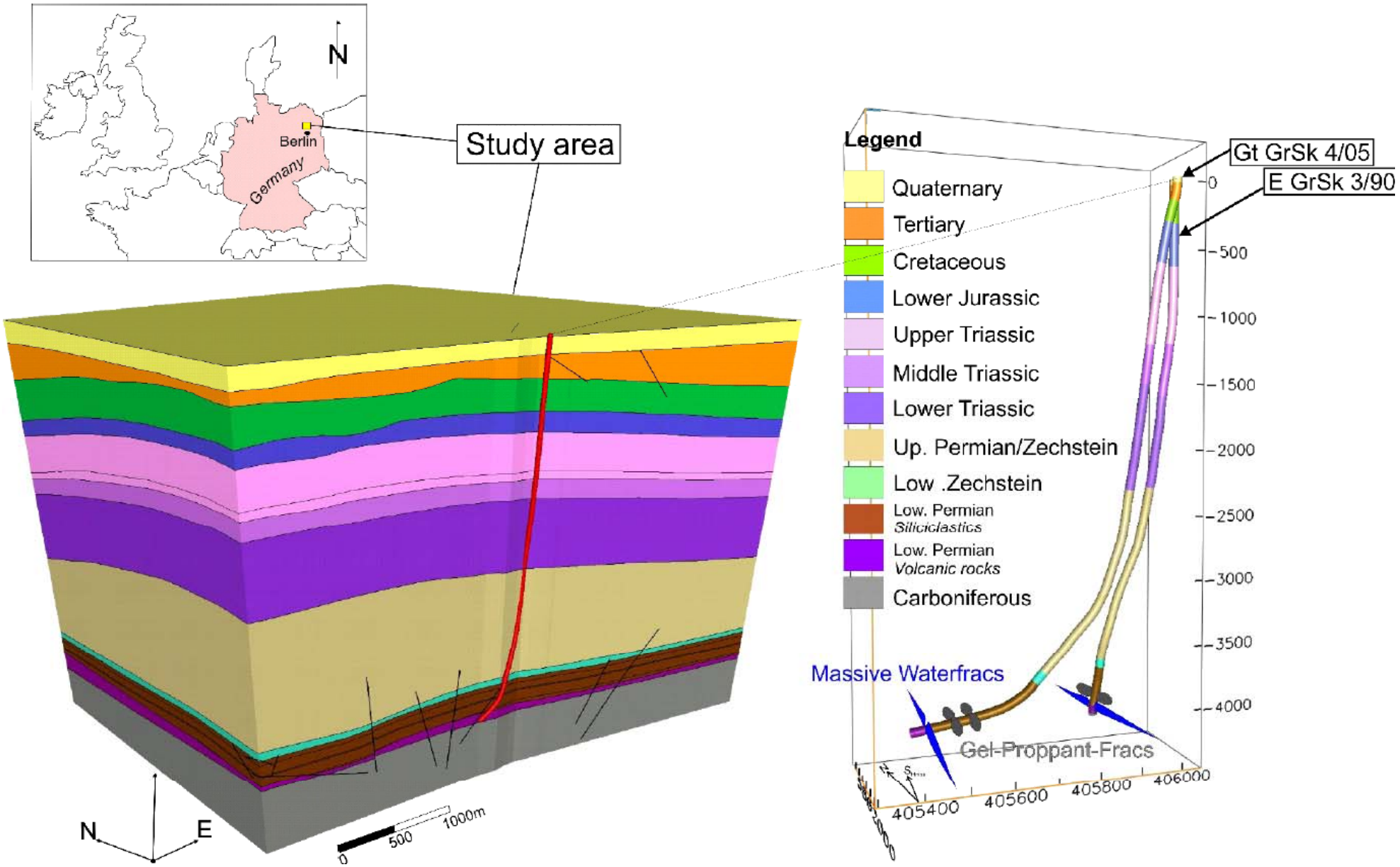


from A. Reinicke

Geological model Groß Schönebeck



well paths and frac orientation Groß Schönebeck site



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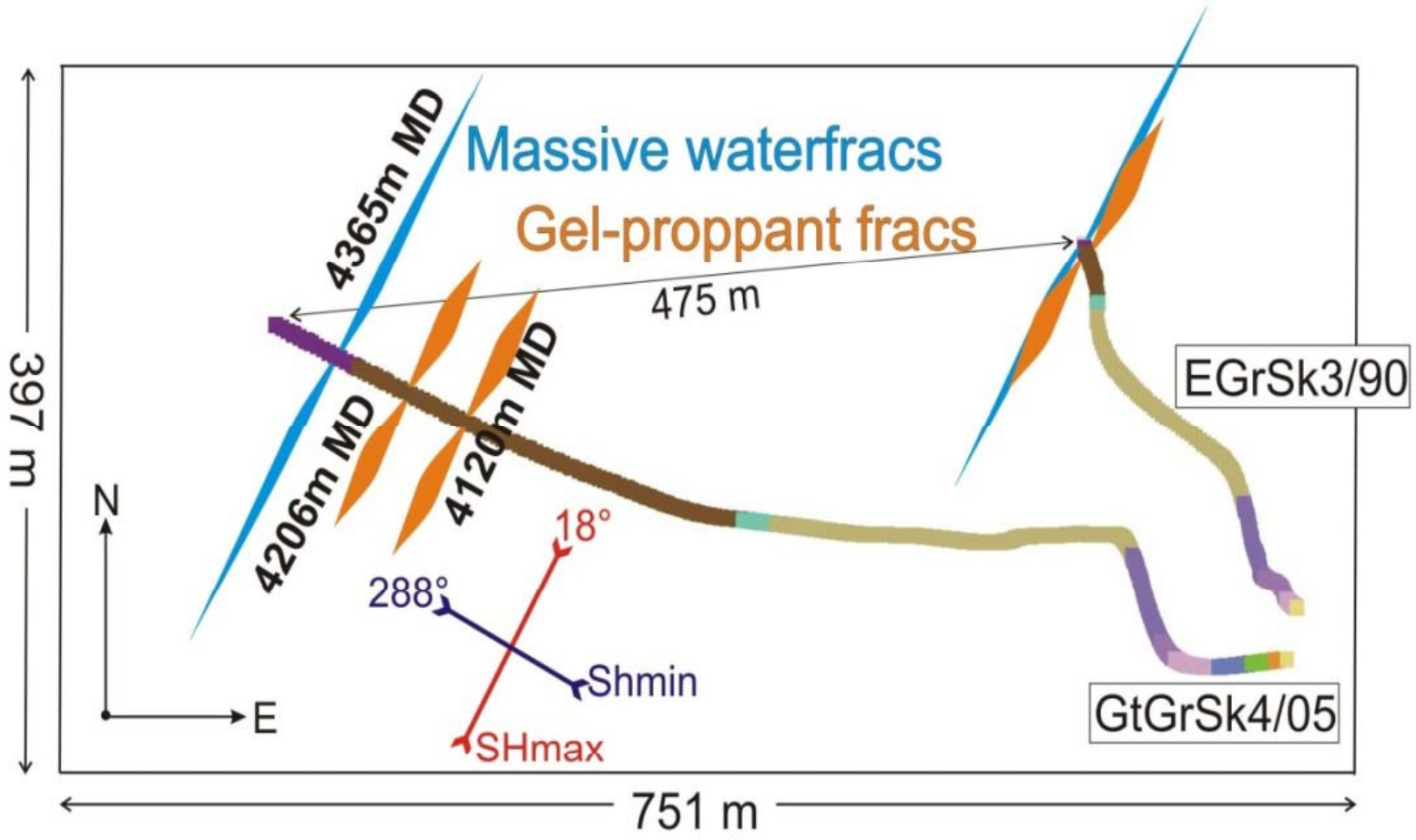
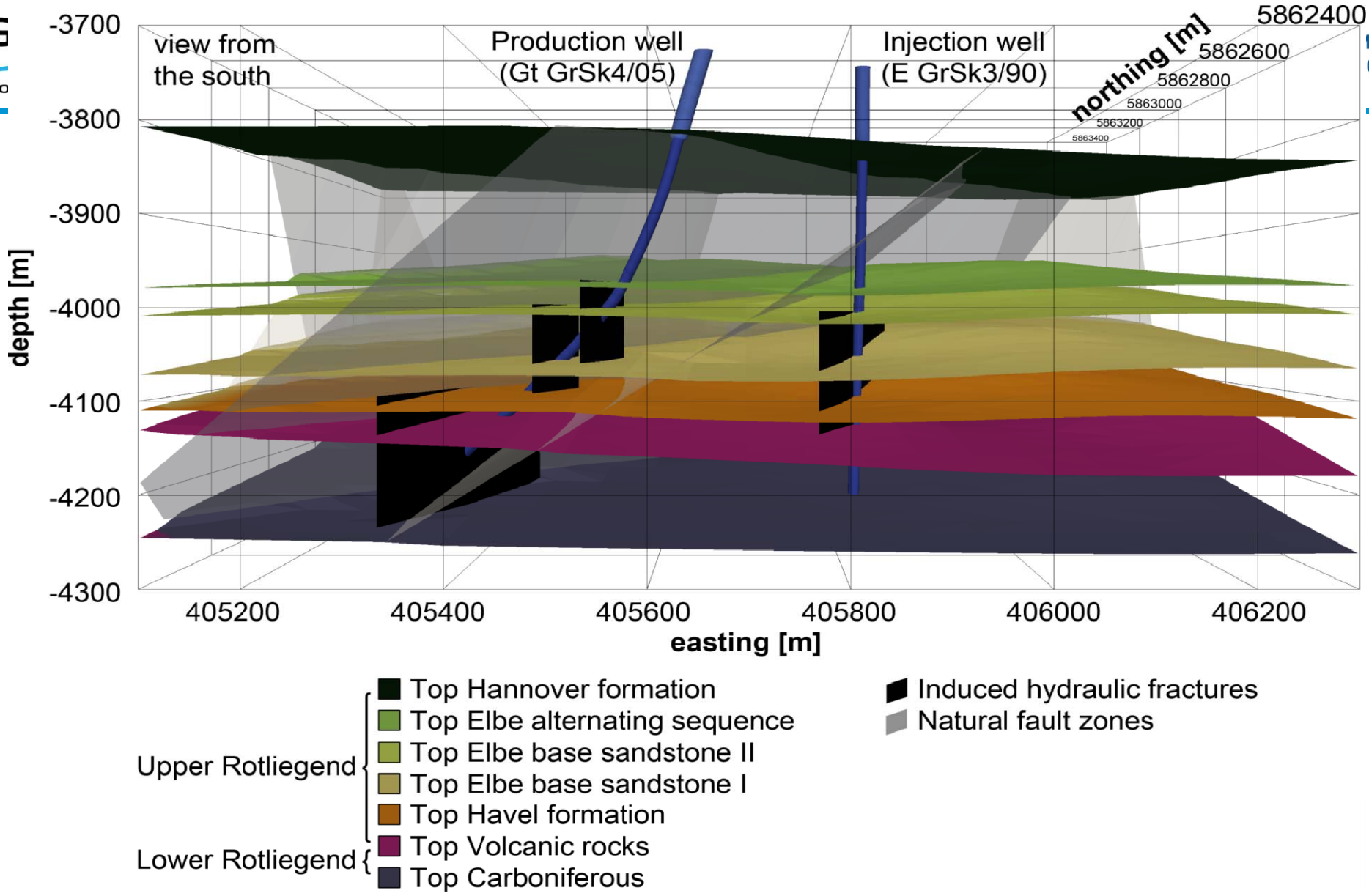
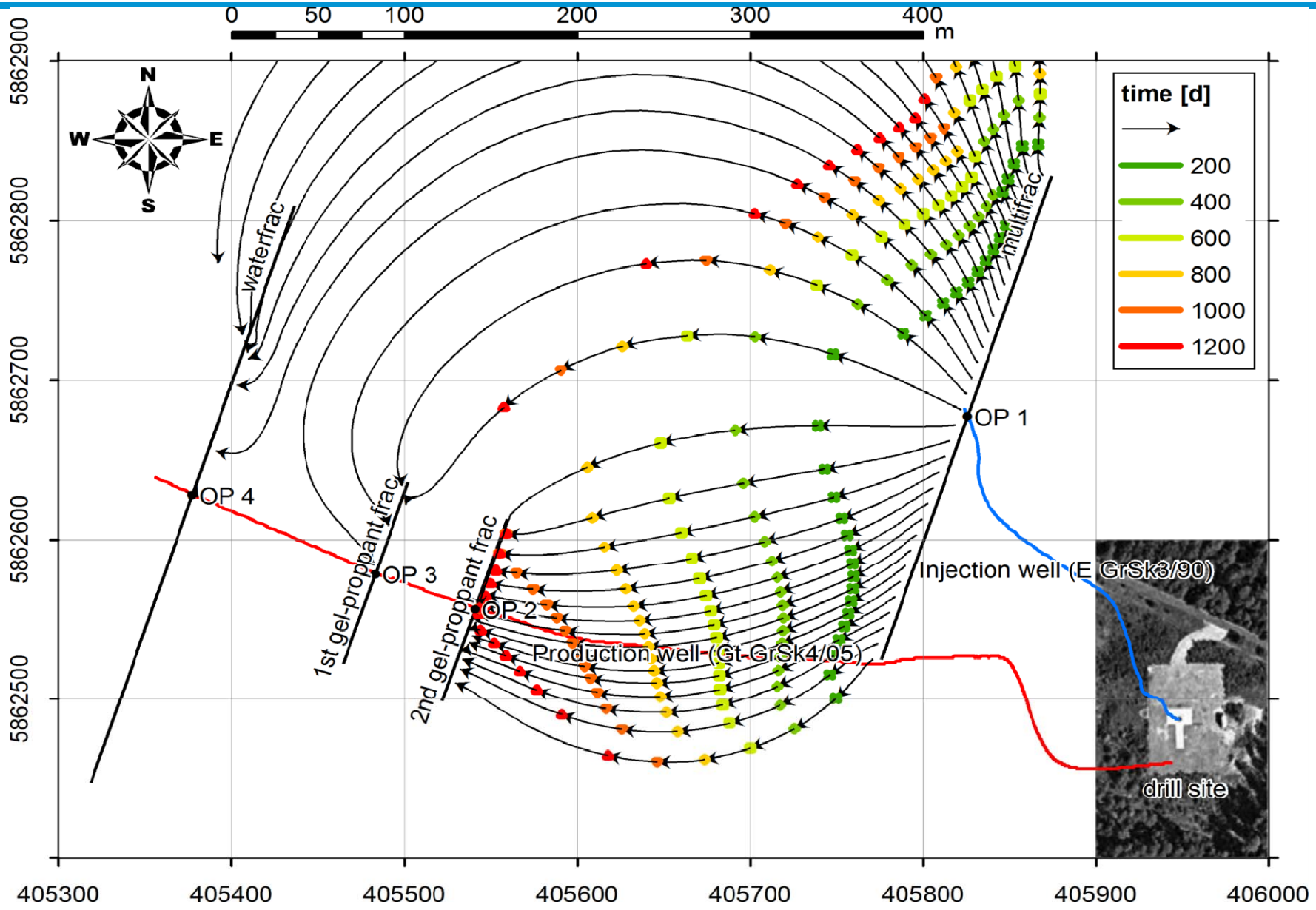


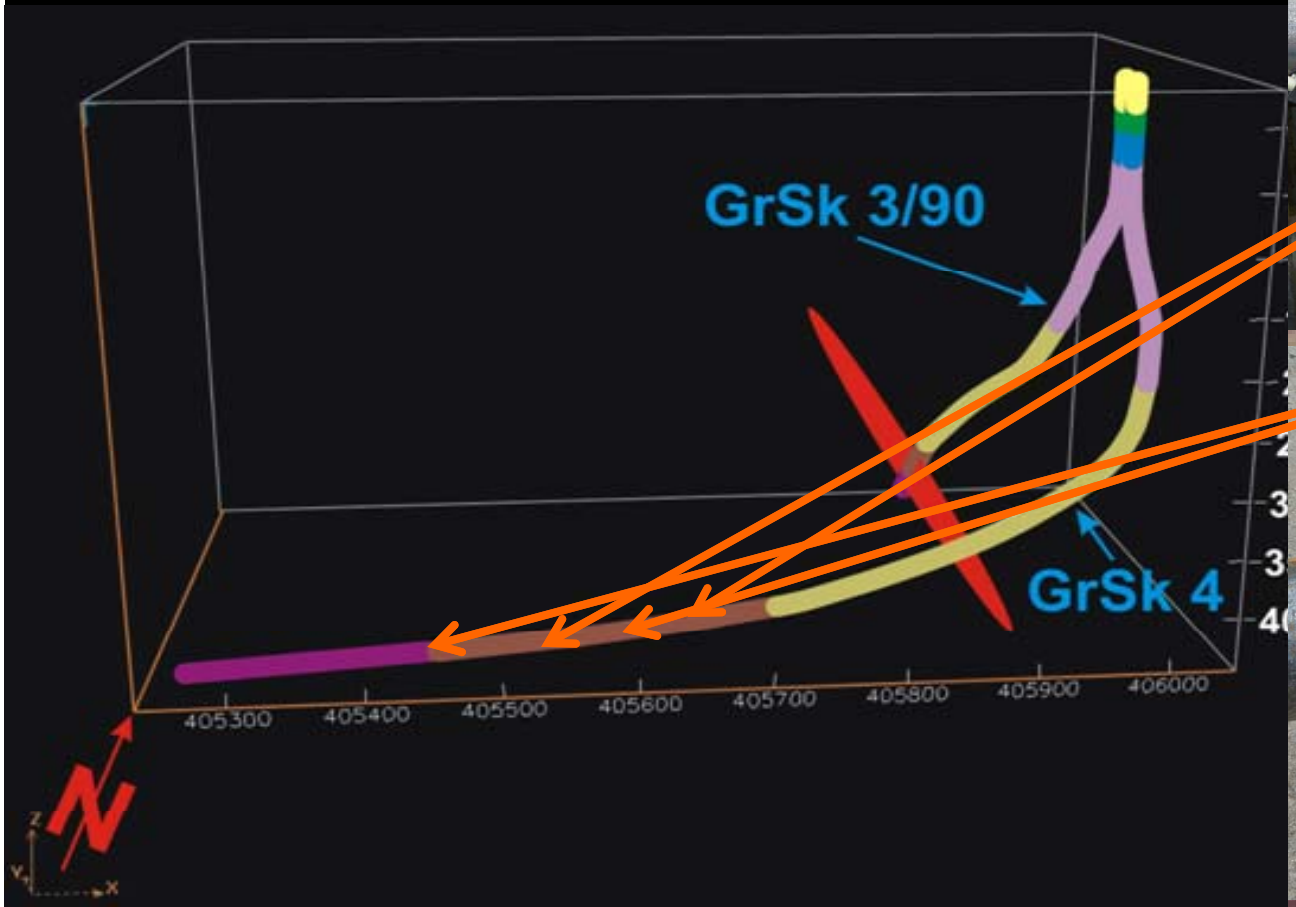


Doublet system Groß Schönebeck

Flow field of doublet system



History of Stimulation Treatments



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Frac Equipment

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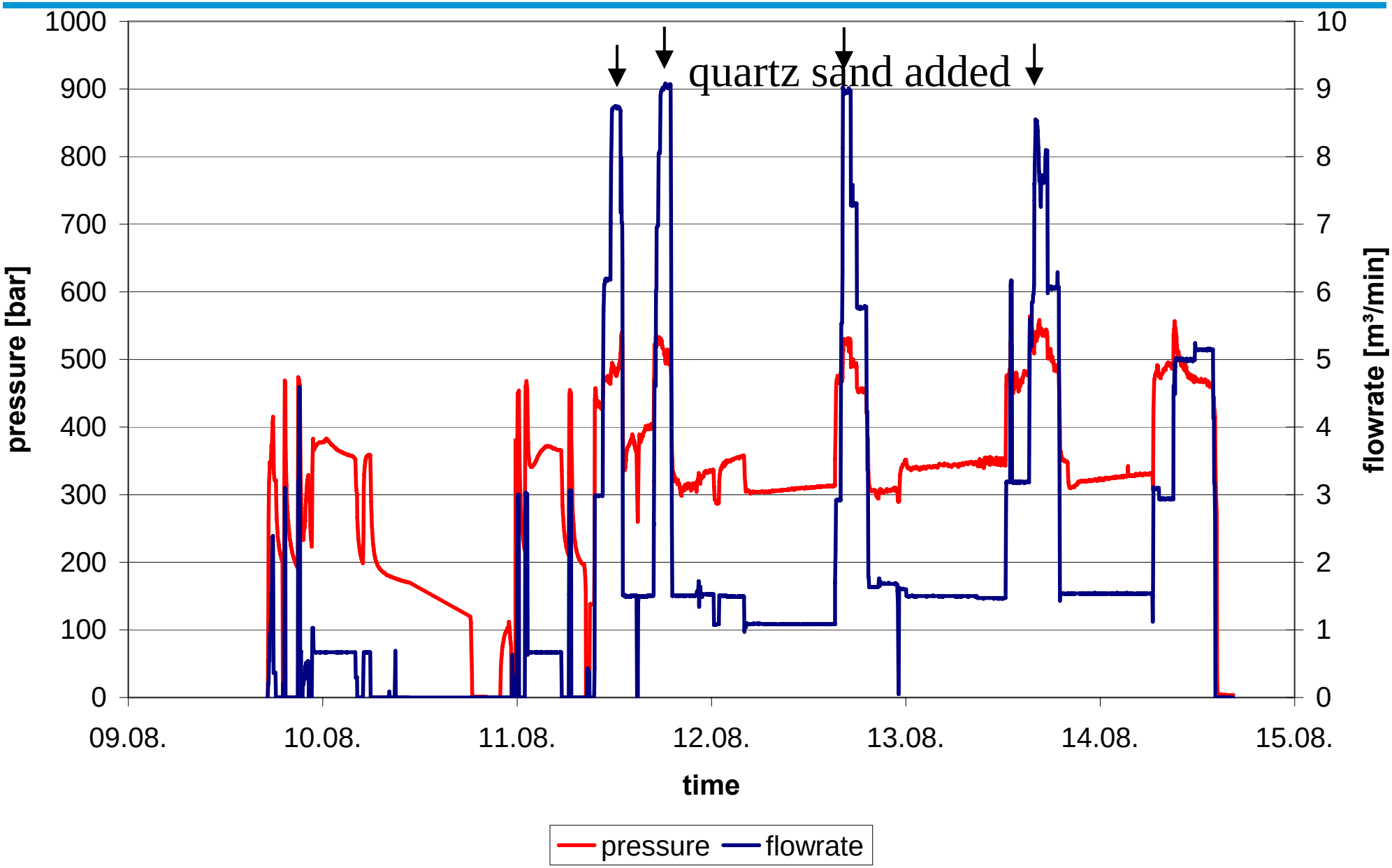
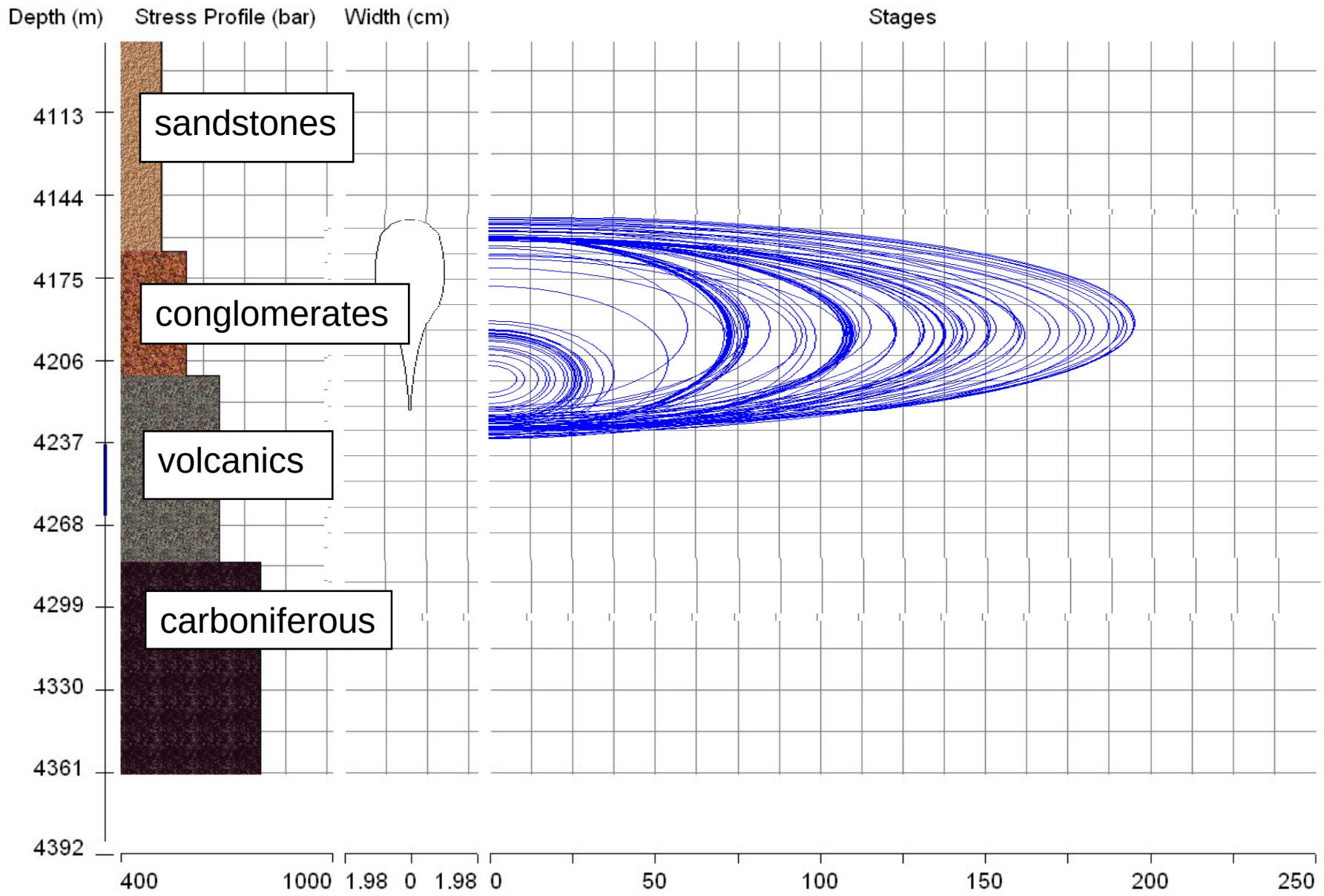
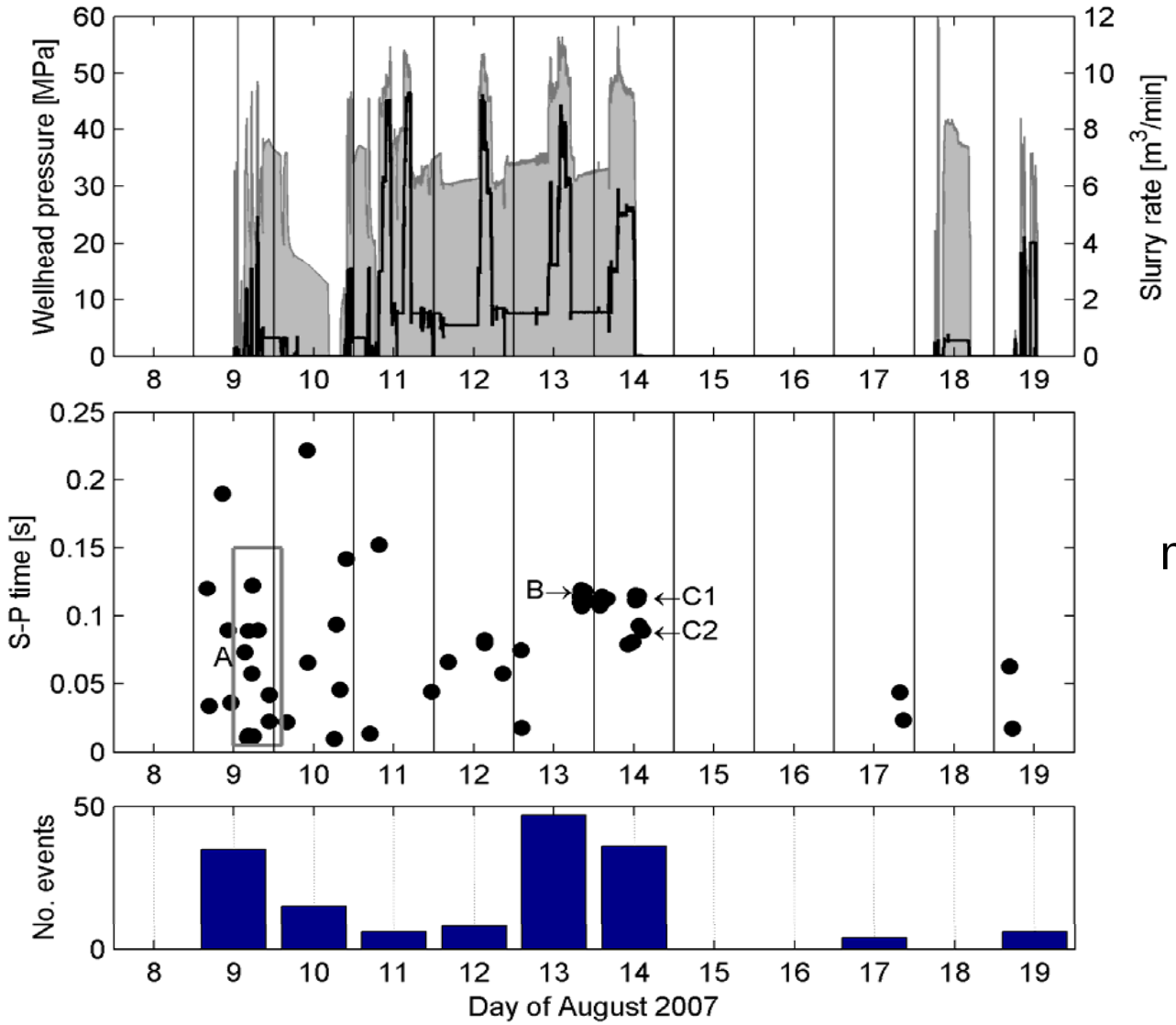
waterfrac treatment



fracture propagation of waterfrac treatment



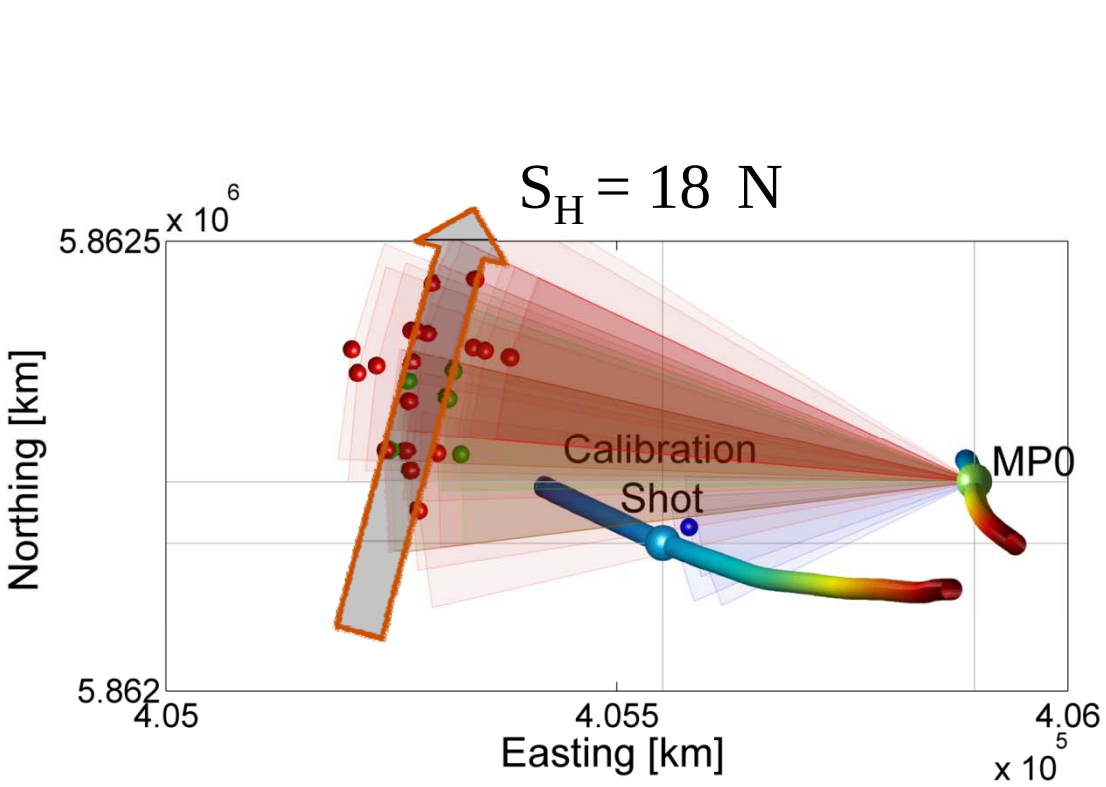
microseismic monitoring

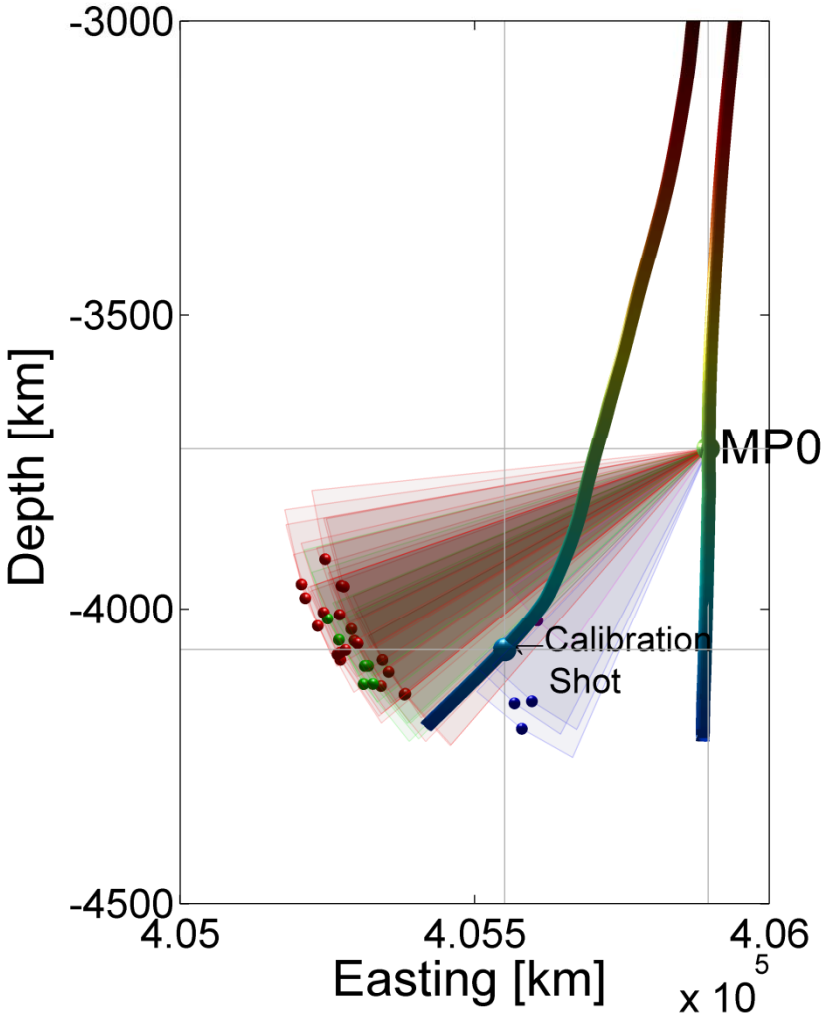


moment magnitude -1... -1.8

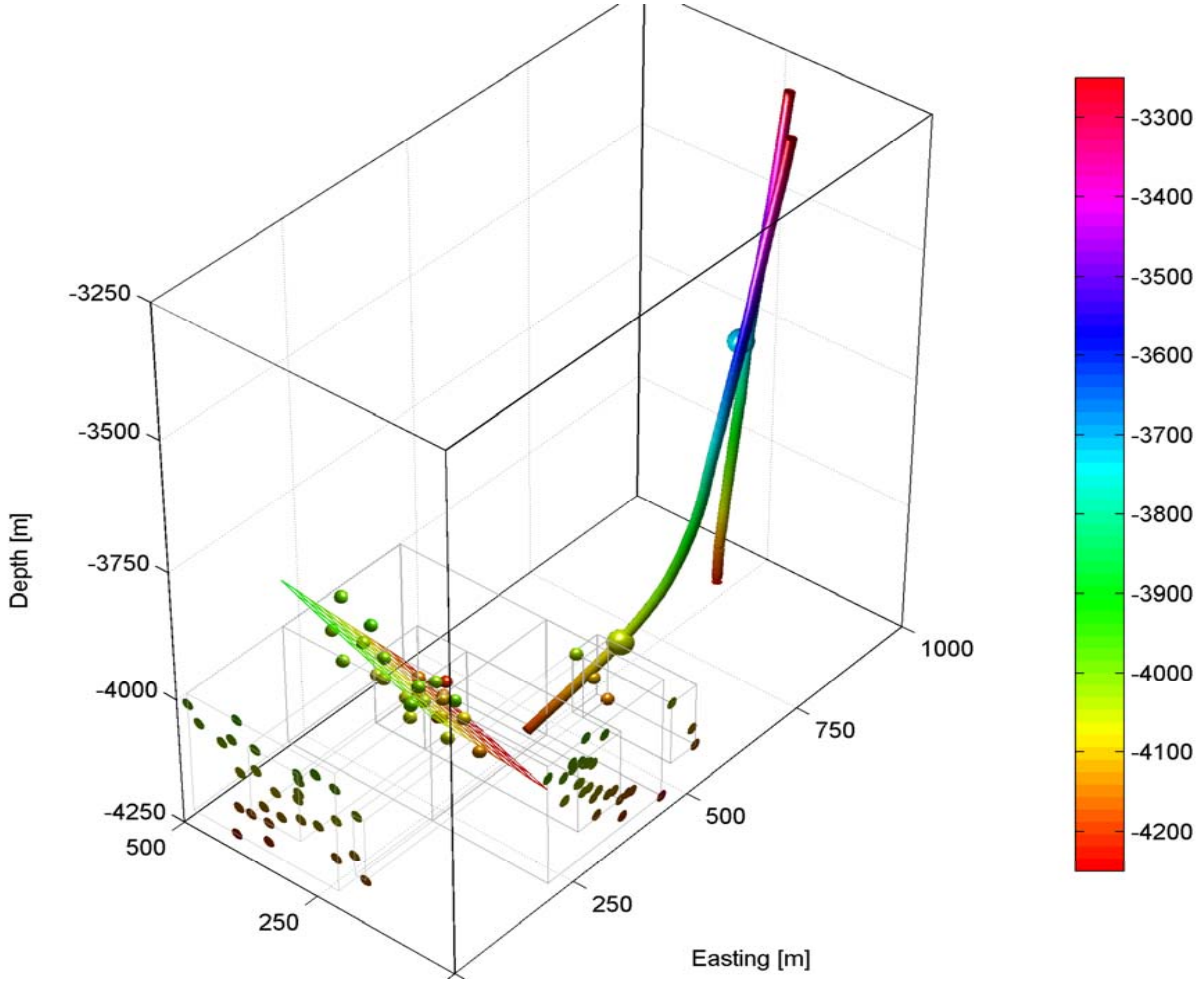
Kwiatek et al., 2010

microseismic monitoring





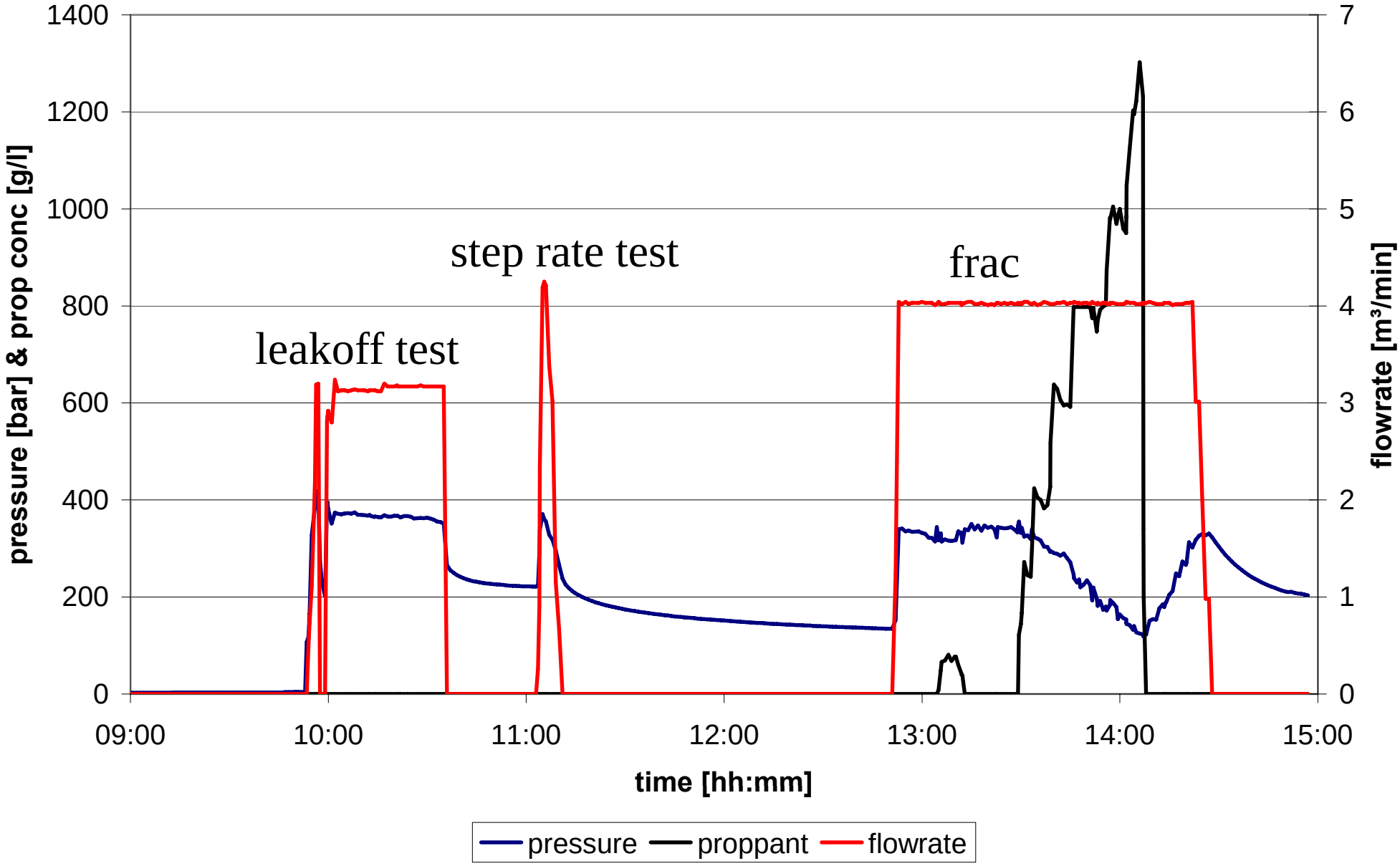
Kwiatek et al., 2010



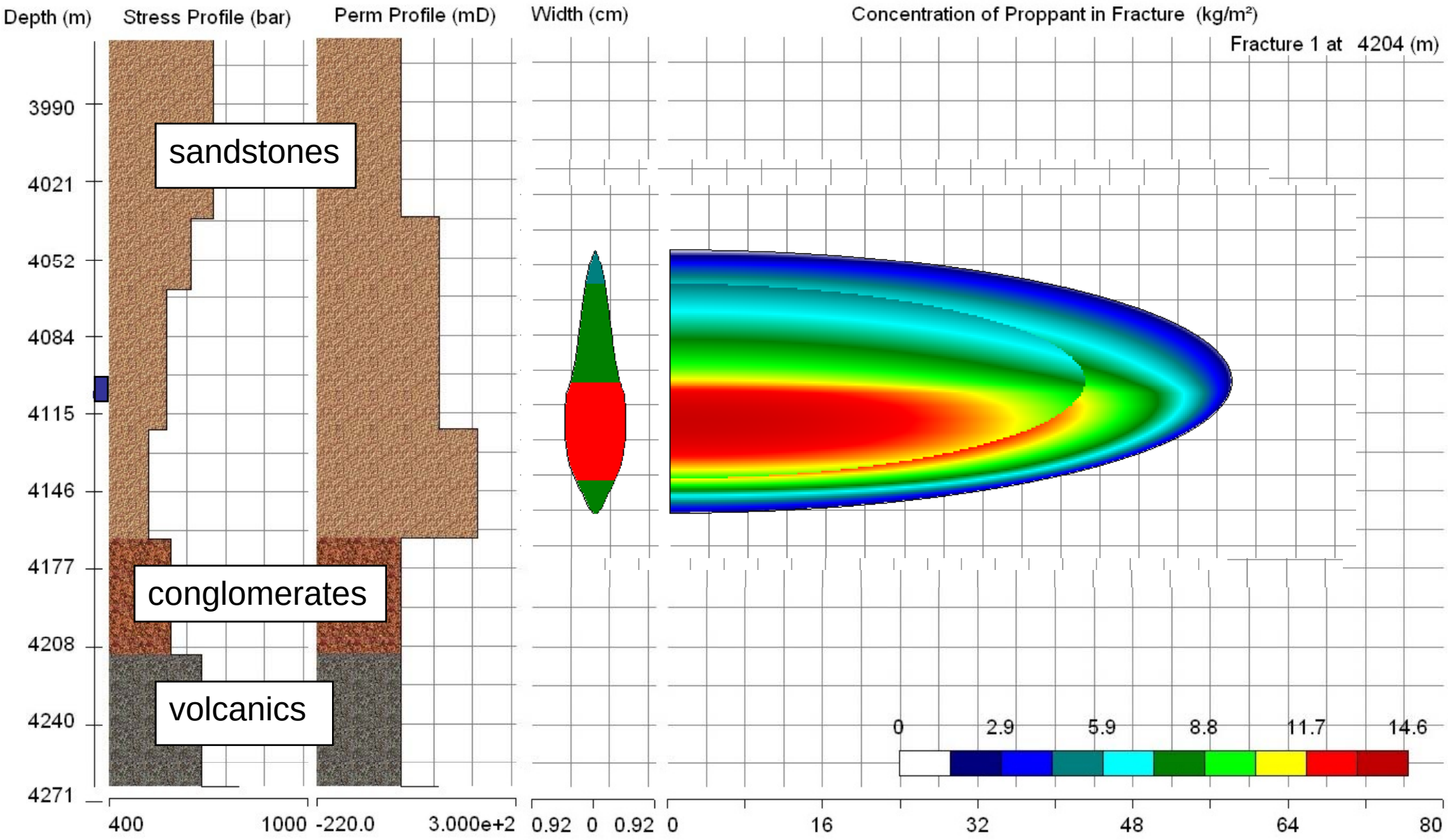
Kwiatek et al.
Acta Geophysica 2010

end of waterfrac treatment

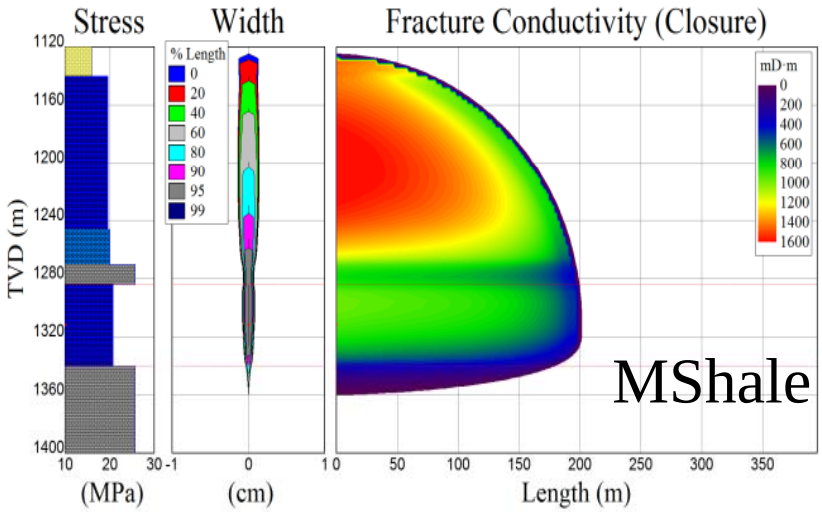
gel proppant treatment



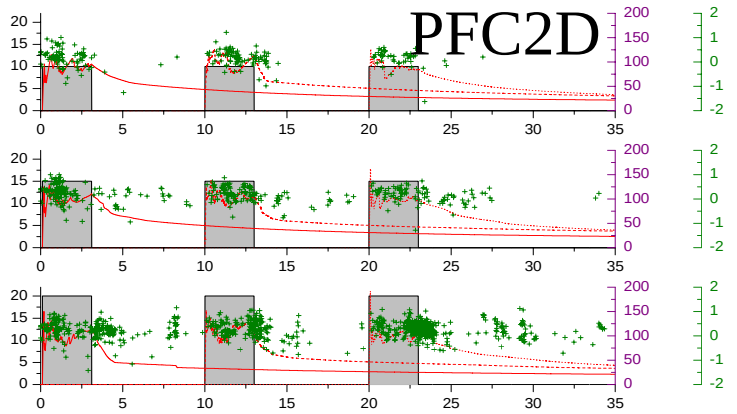
fracture propagation of gel-proppant treatment

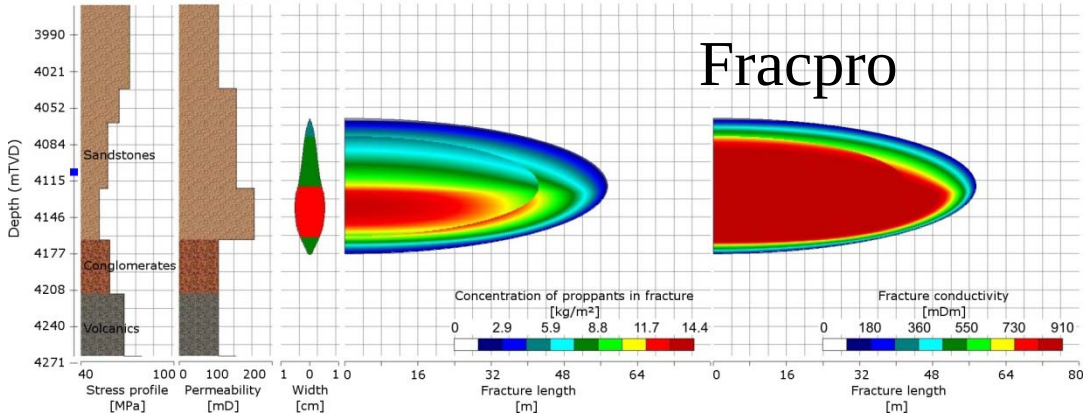


Hydraulic fracturing

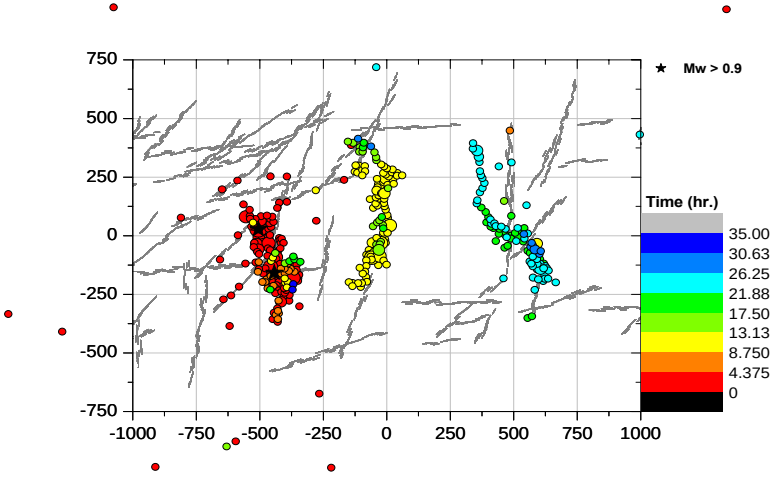


Hofmann et al., 2013





Zimmermann & Reinicke, 2010

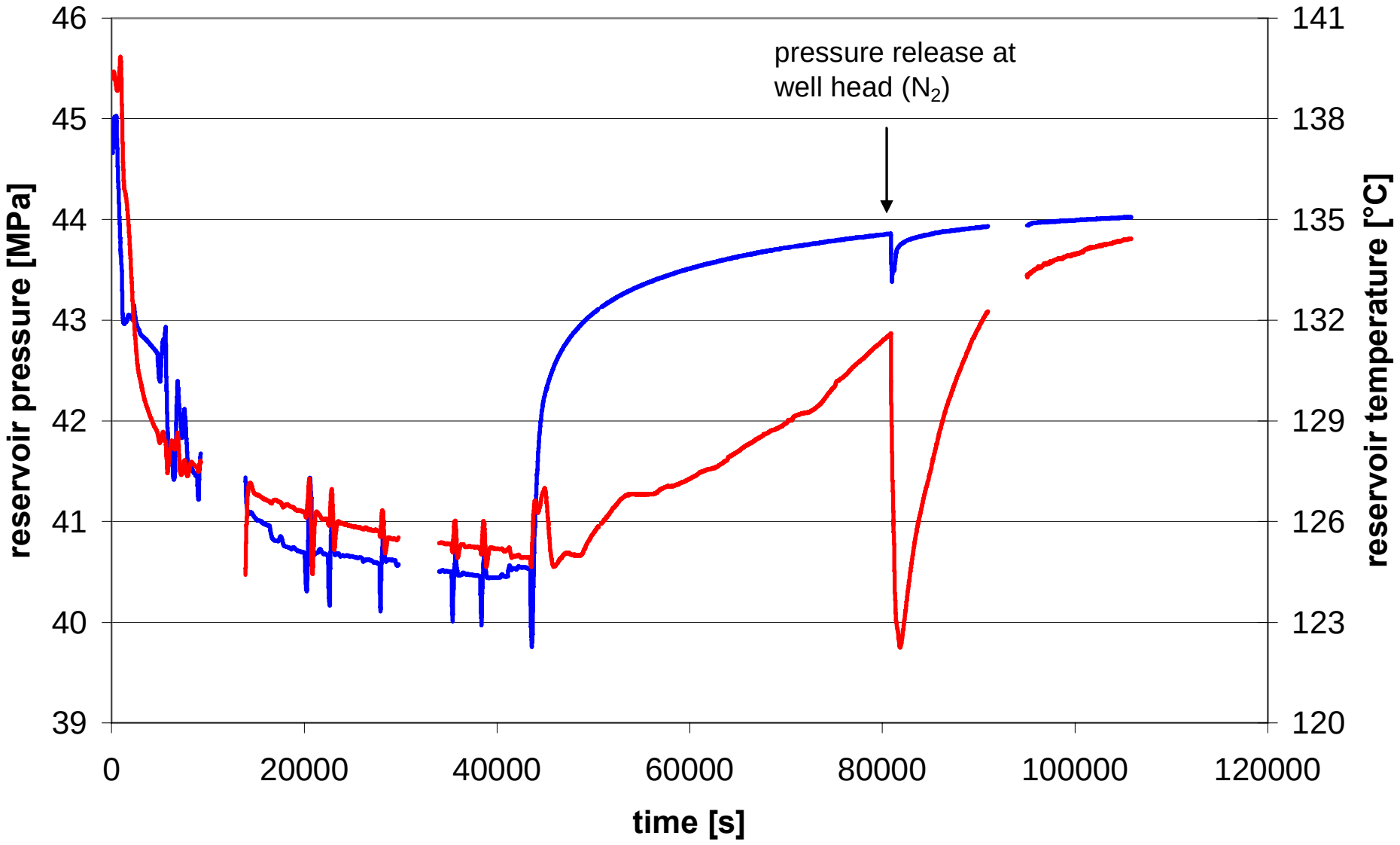


Yoon et al., 2013

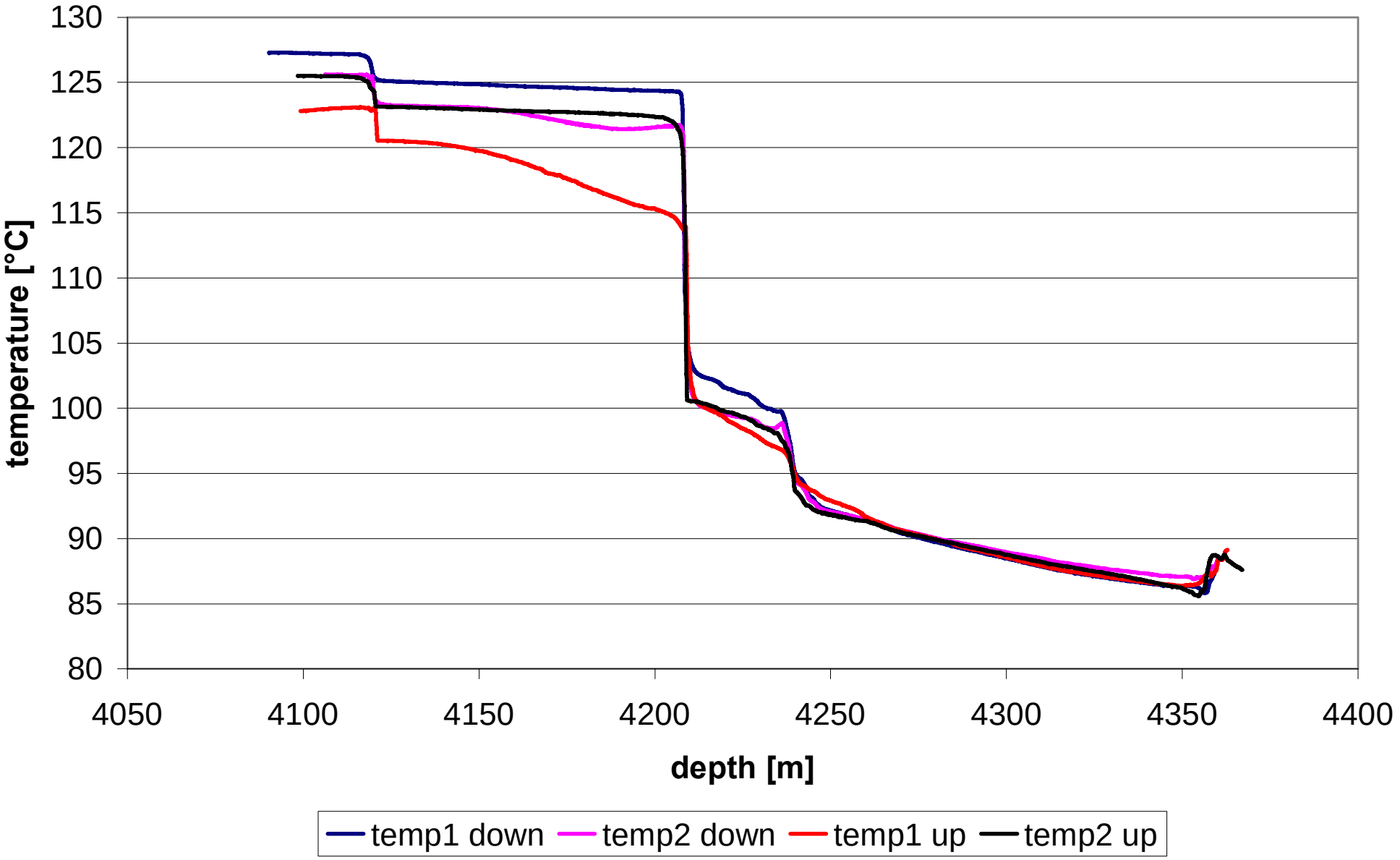
production test (CLT)

mean flowrate = 30.2 m^3/h

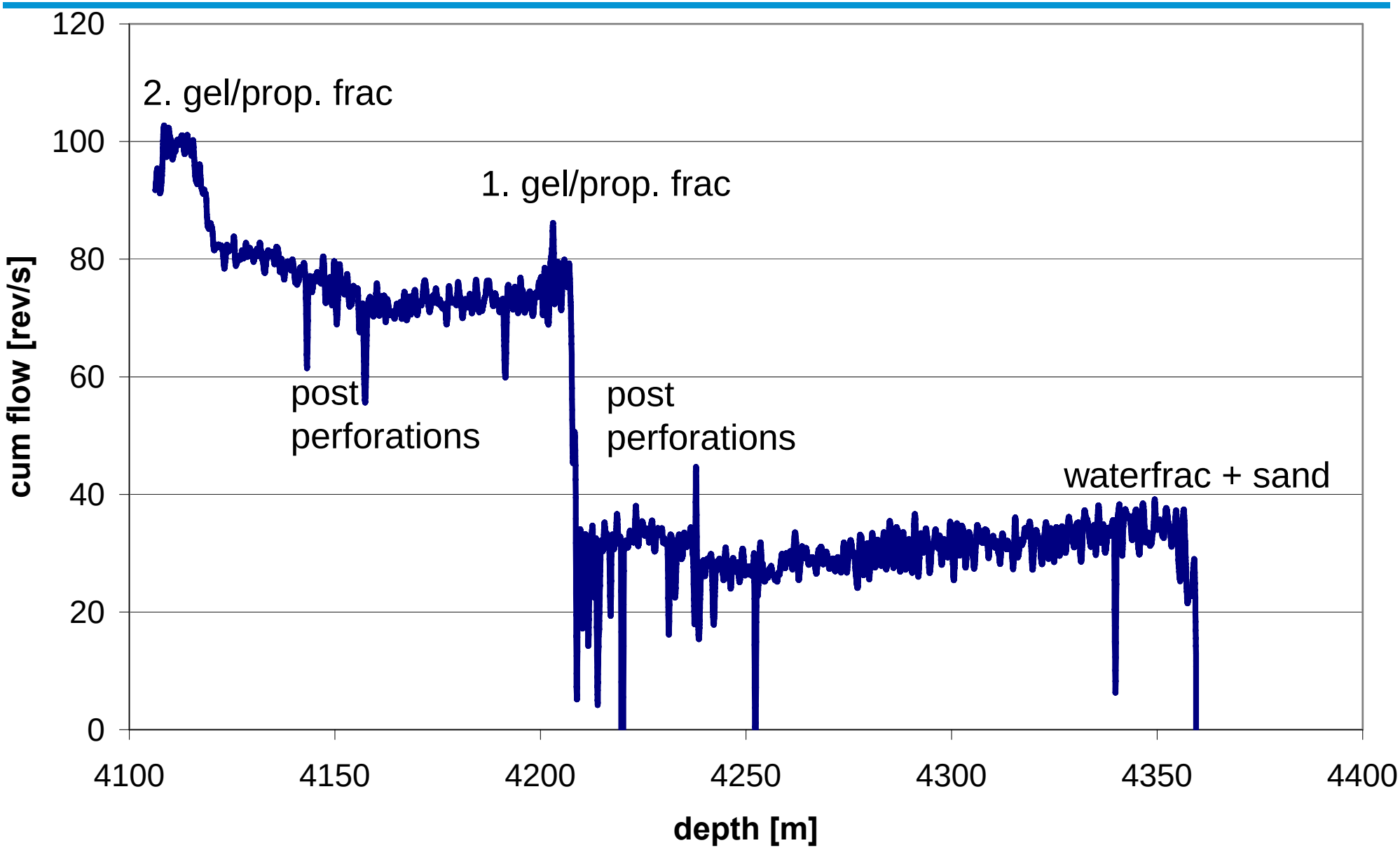
duration = 11.8 h production + 17.3 h shut-in


pressure release at
well head (N_2)
reservoir pressure [MPa]
reservoir temperature [°C]
time [s]
46
45
44
43
42
41
40
39
141
138
135
132
129
126
123
120
0
20000
40000
60000
80000
100000
120000

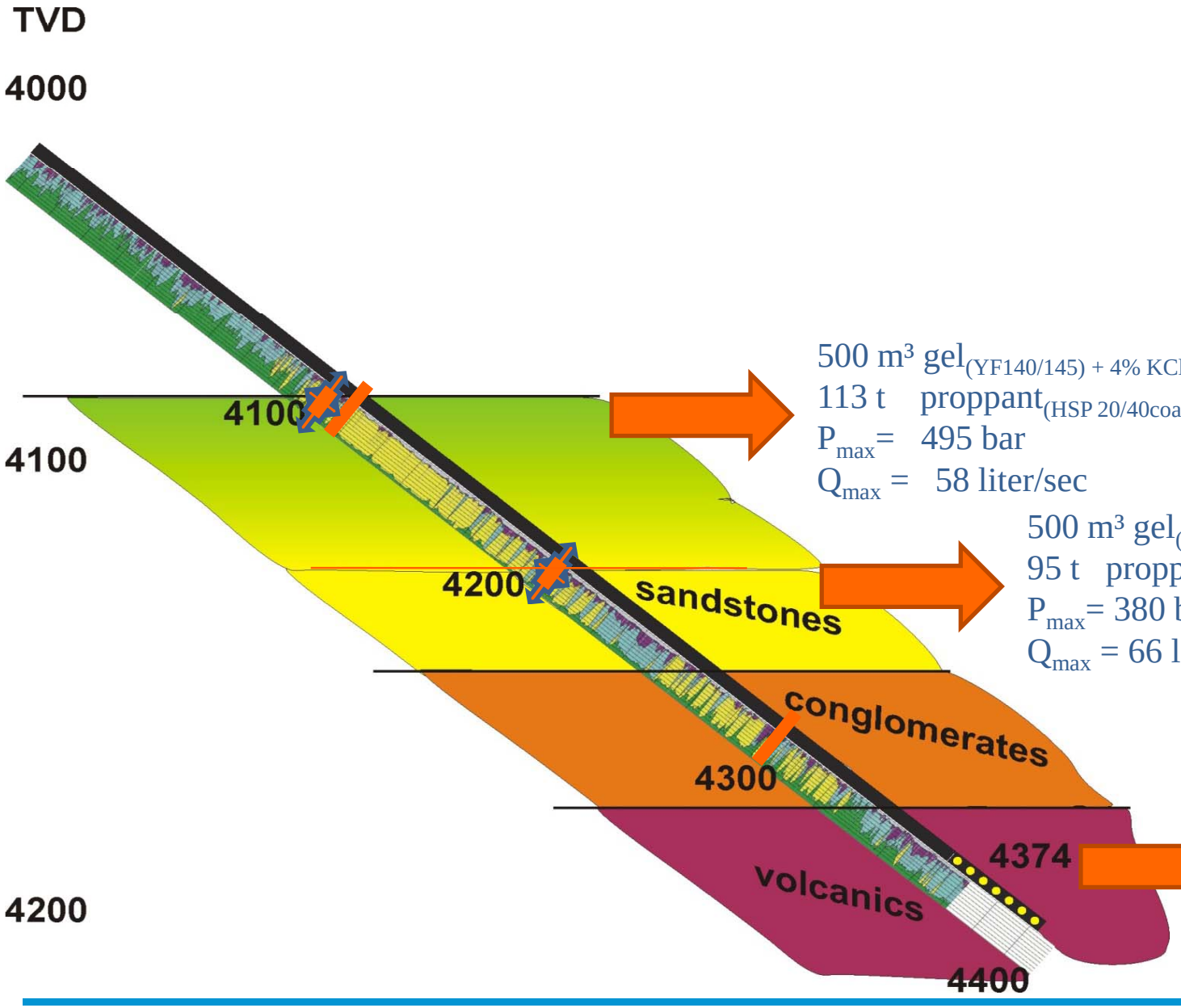
temperature logs during CLT



flowmeter logs during CLT



summary of treatments



500 m³ $gel_{(YF140/145) + 4\% KCl}$
113 t proppant$_{(HSP 20/40coated/uncoated)}$
P_{max}= 495 bar
Q_{max} = 58 liter/sec

500 m³ $gel_{(YF140/145) + 4\% KCl}$
95 t proppant$_{(HSP 20/40coated/uncoated)}$
P_{max}= 380 bar
Q_{max} = 66 liter/sec.

13000 m³ $water_{(pH5)}$
24 t sand
P_{max} = 586 bar
Q_{max} = 150 liter/sec.

acidizing and testing (CLT) 2009

acidizing and testing (CLT) 2009

coil tubing unit

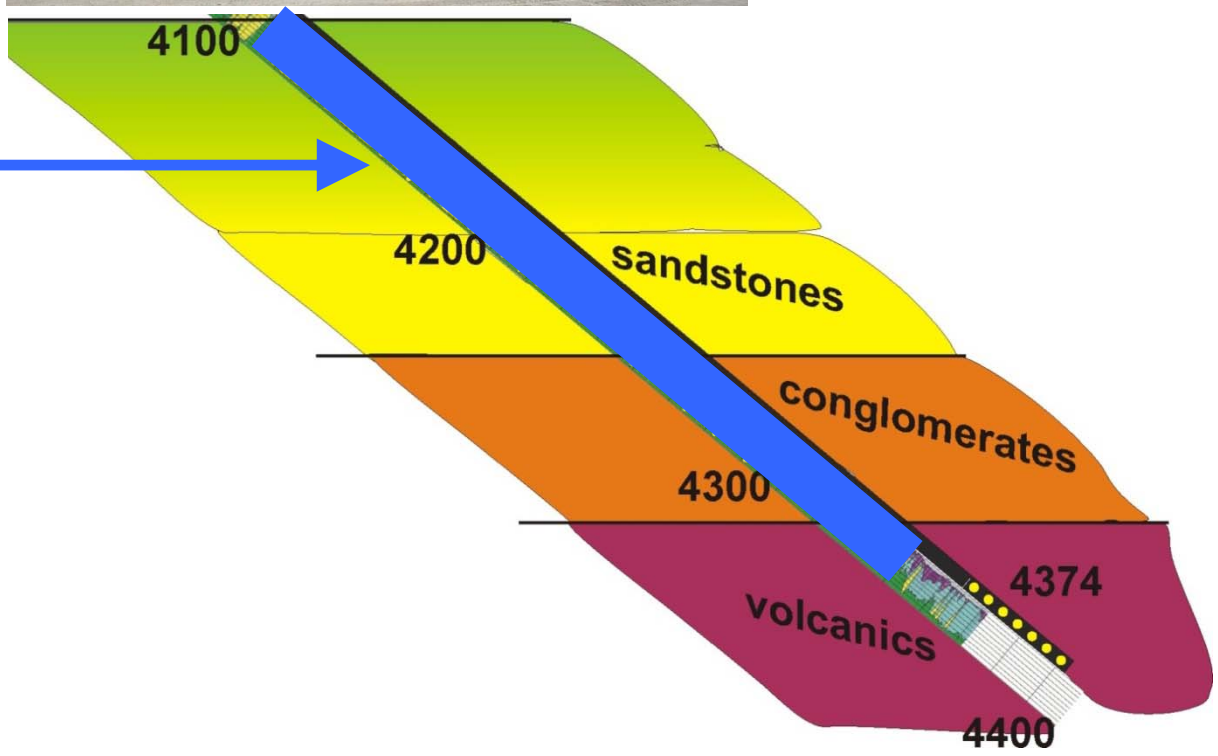
- reel diameter 2”
- reel length 5000 m

acid placement

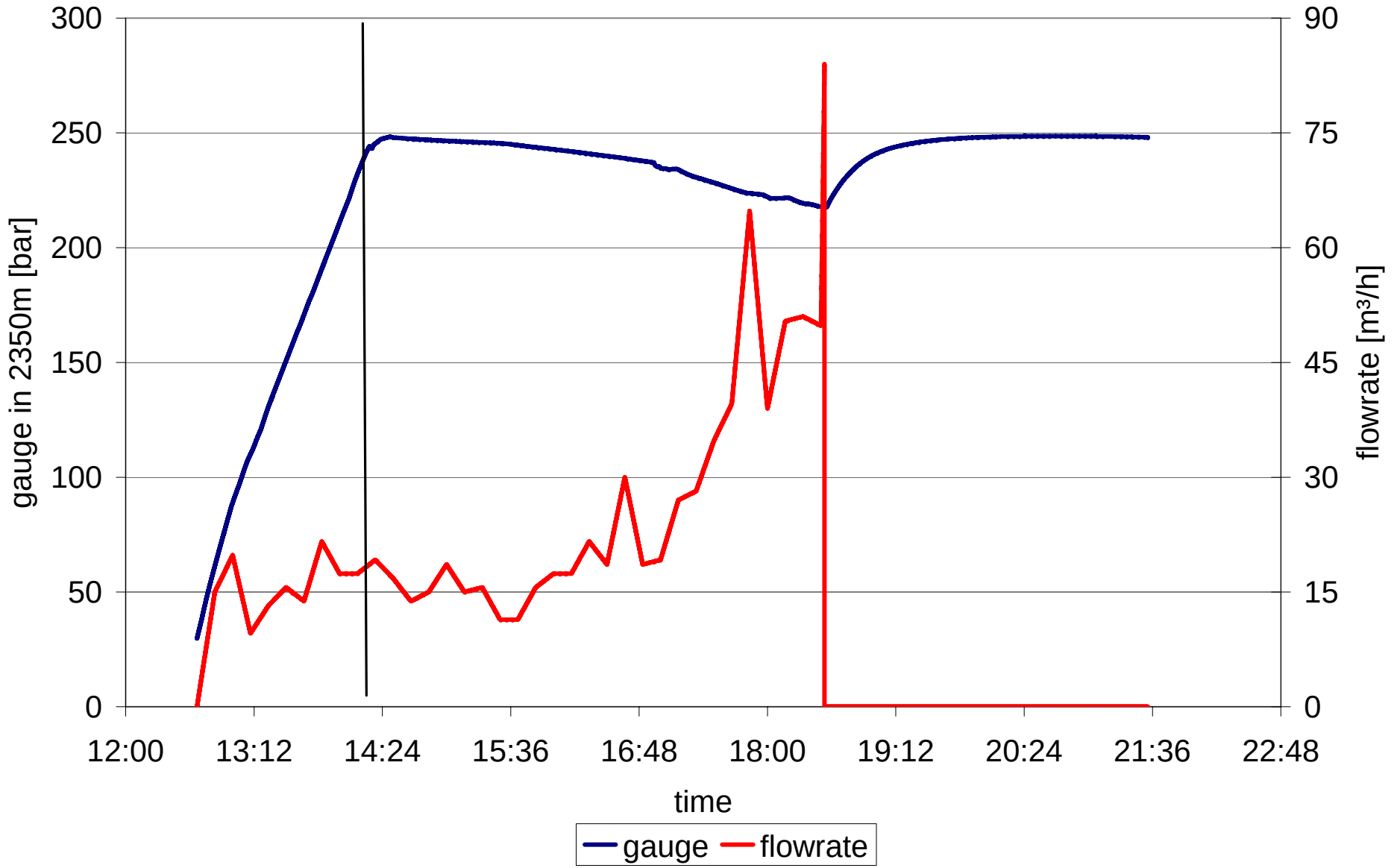
- 10 m³ of hydrochloric acid
- 7.5 % concentration
- between 4360 - 4100 m MD
- for 30 minutes

casing lift test (CLT)

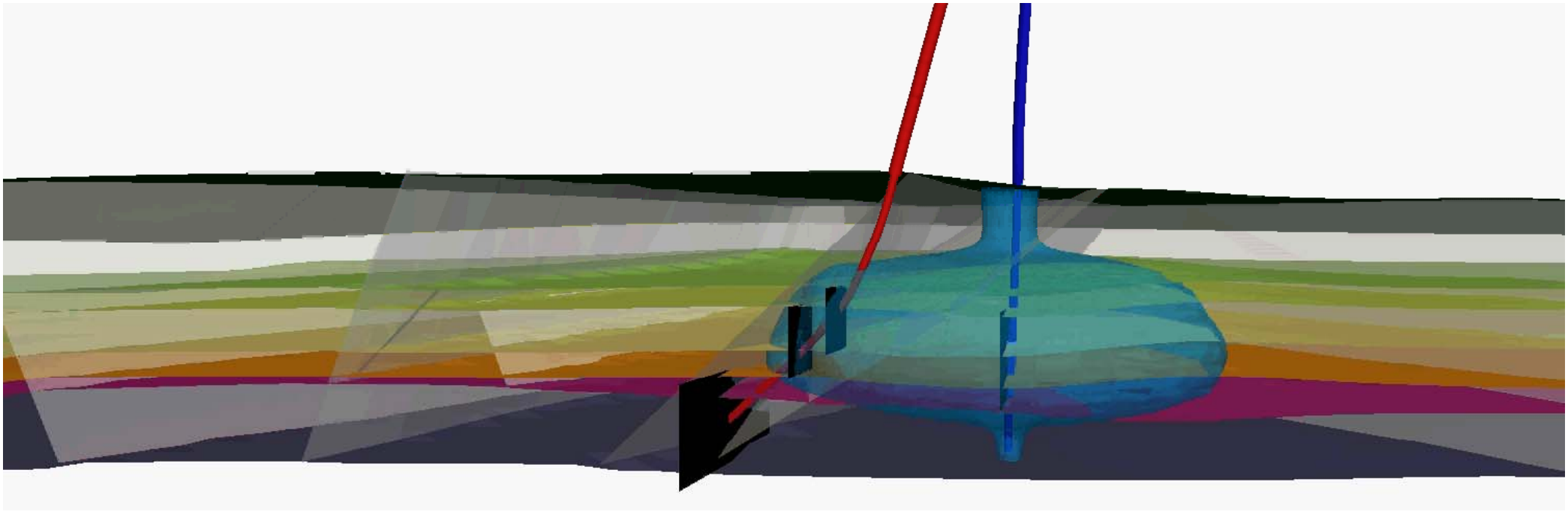
- pressure gauge in 2350 m
- duration 4 hours
- total volume 140 m³



casing lift test

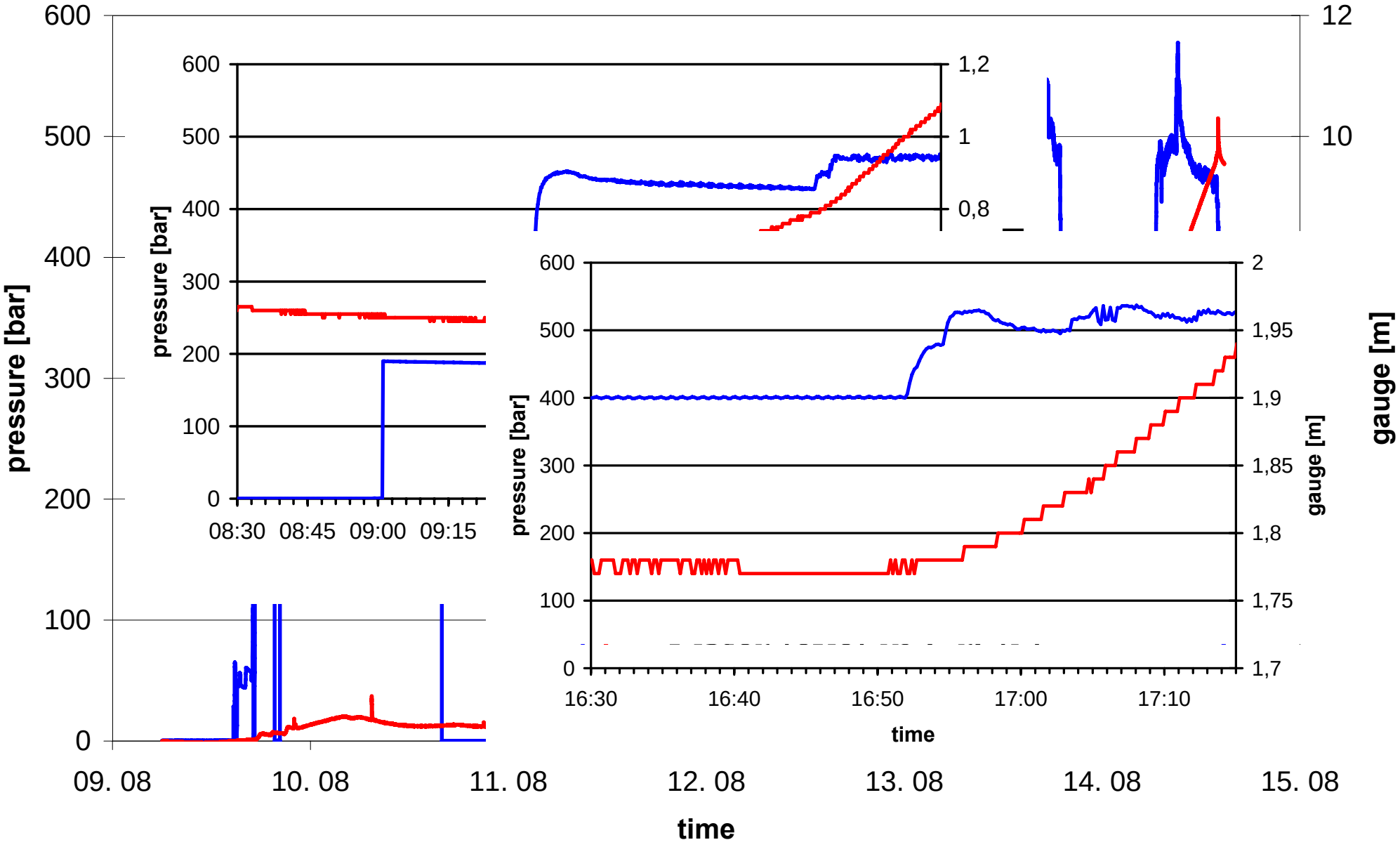


injection - production

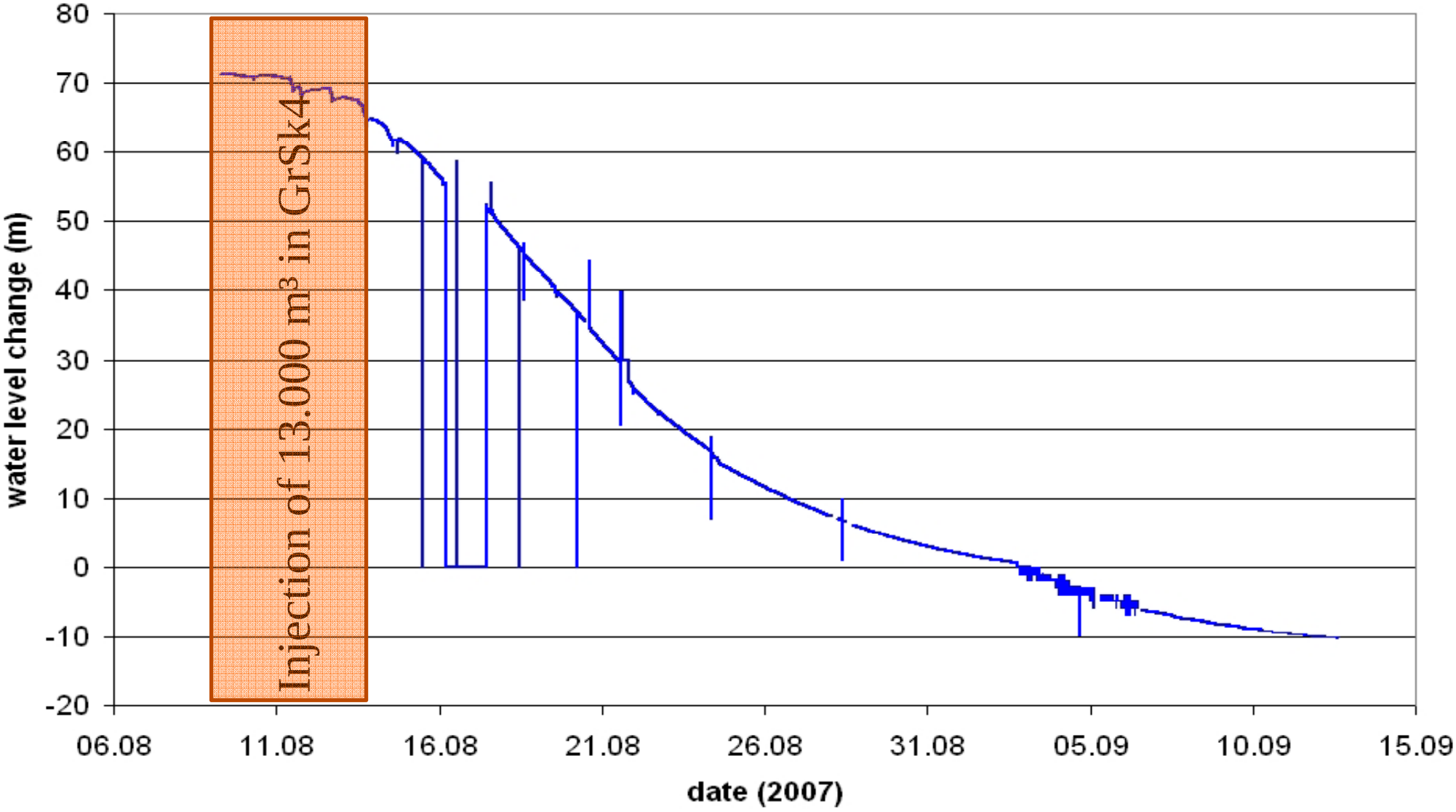


Propagation of cold water front (135°C) around the injection well (75m³/h; 70°C) over a period of 30 years
(Blöcher et al., 2009)

interference with GrSk3

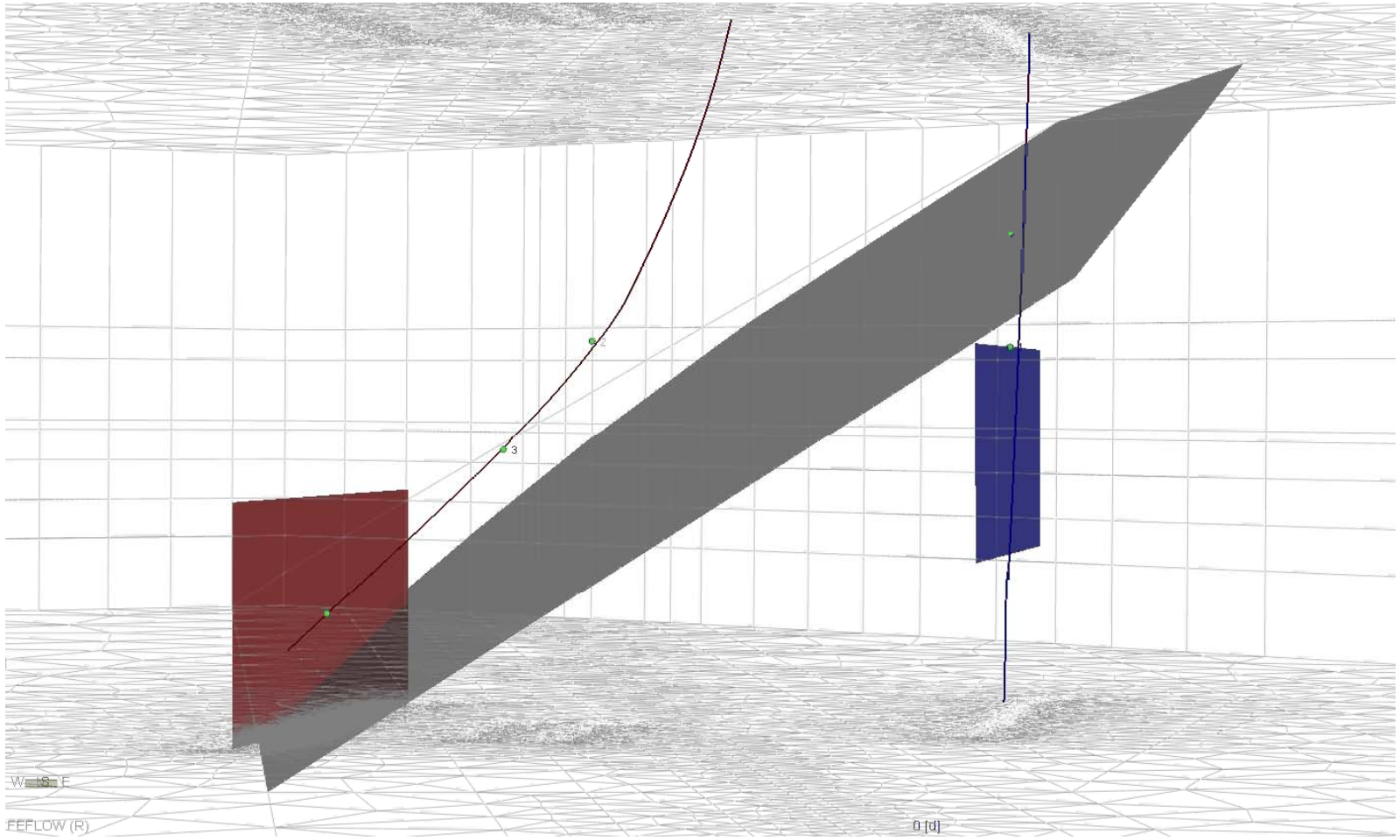


Communication 4/05 with 3/90 during waterfrac stimulation 2007

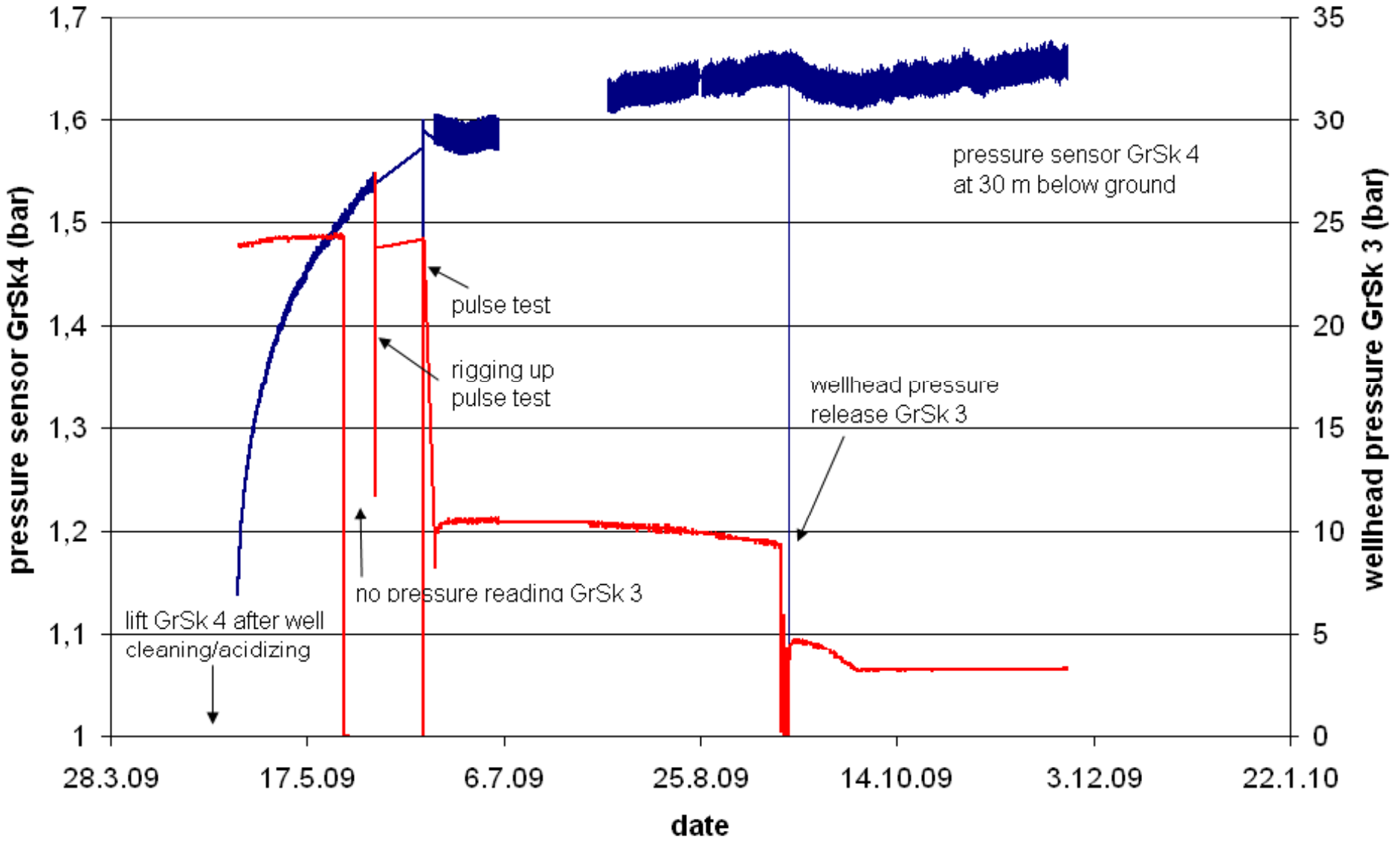


Pressure increase due to stimulation treatment

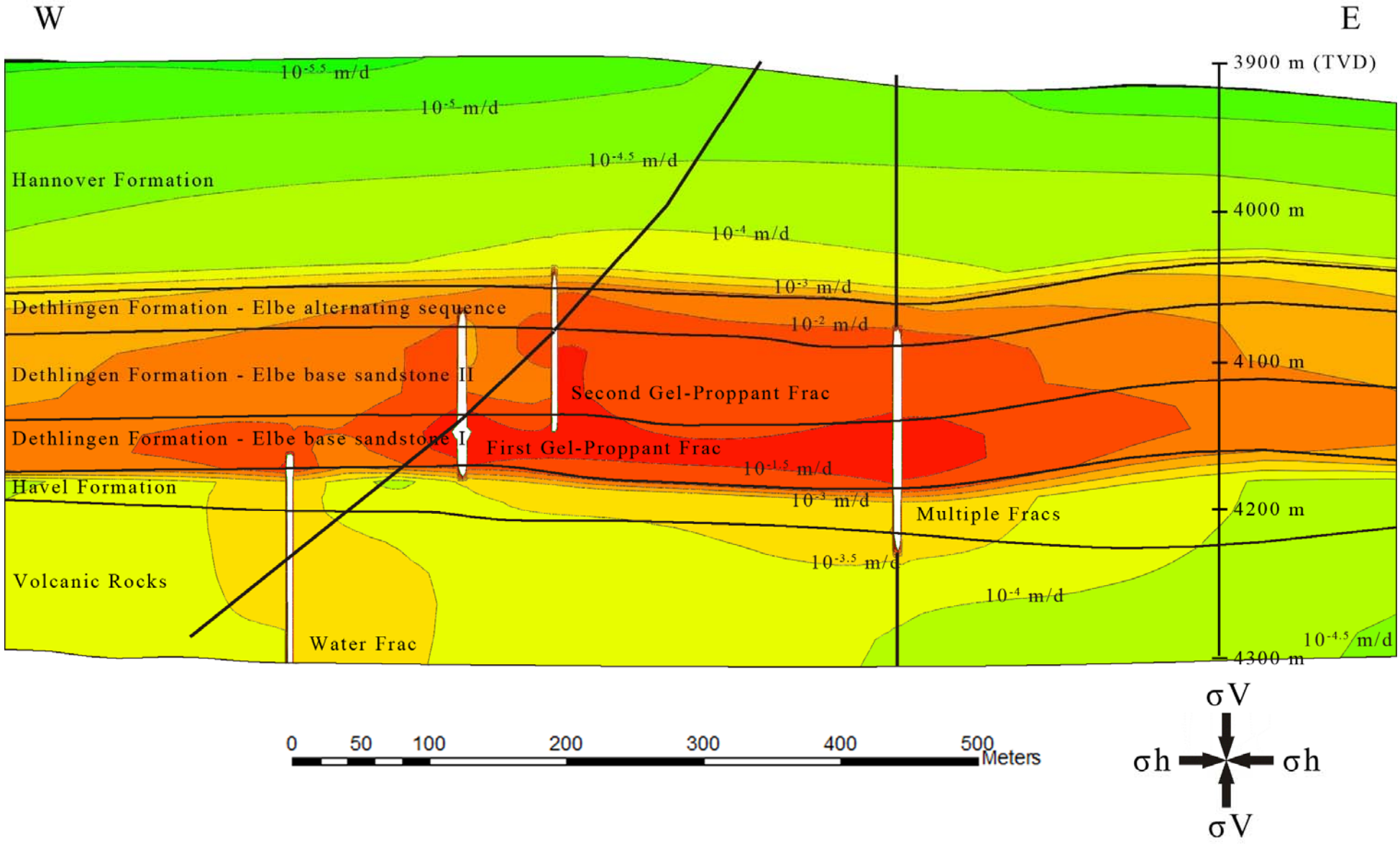
- Discrete flow paths influence significantly the flow and temperature field of the reservoir



interference with GrSk4



flow between doublet



conclusions

- Stimulation methods should be laid out individually depending on:
  - Rock properties
  - Stratigraphic sequences
  - Structural geological settings, stress field
  - Shear potential and self propping effect

- Application in Groß Schönebeck:
  - Waterfrac stimulation in volcanic rocks
  - 2 gel-proppant stimulations in sandstones
  - Acid stimulation in sandstones

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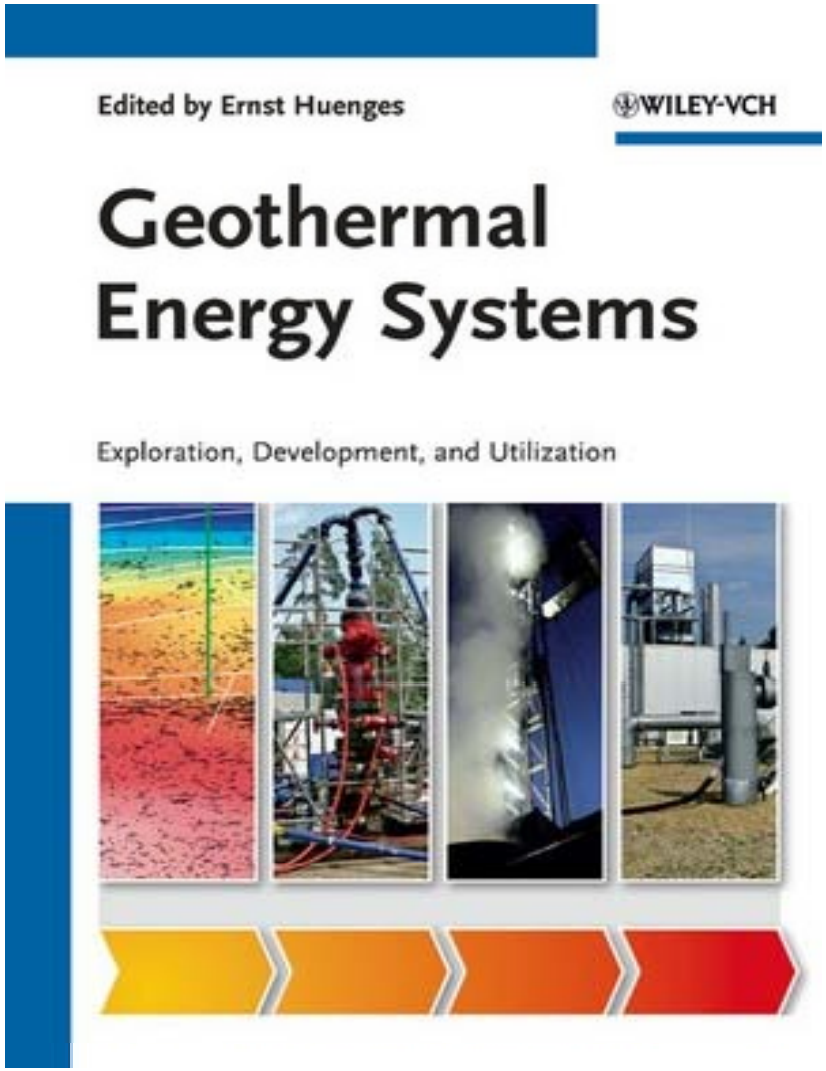

Short description

Experts in high temperature reservoirs -- in shallow and deep horizons in various geological situations in Europe -- provide basic, yet detailed knowledge on the utilization of European geothermal resources.

From the contents

Reservoir Definition
Exploration Methods
Drilling into Geothermal Reservoirs
Enhancing Geothermal Reservoirs
Geothermal Reservoir Simulation
Energetic Use of EGS Reservoirs
Economic Performance and Environmental Assessment